INVESTIGATION

OF THE

POWERS OF THE PRISMATIC COLOURS TO HEAT AND ILLUMINATE OBJECTS, &c.

EXPERIMENTS

ON THE

REFRANGIBILITY OF THE INVISIBLE RAYS OF THE SUN.

EXPERIMENTS ON THE SOLAR,

AND ON THE

TERRESTRIAL RAYS THAT OCCASION HEAT, &c.

BY

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No. 45.

INVESTIGATION OF THE POWERS OF THE PRISMATIC COLOURS, &c.

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It is sometimes of great use in natural philosophy, to doubt of things that are commonly taken for granted; especially as the means of resolving any doubt, when once it is entertained, are often within our reach. We may therefore say, that any experiment which leads us to investigate the truth of what was before admitted upon trust, may become of great utility to natural knowledge. Thus, for instance, when we see the effect of the condensation of the sun's rays in the focus of a burning lens, it seems to be natural to suppose, that every one of the united rays contributes its proportional share to the intensity of the heat which is produced; and we should probably think it highly absurd, if it were asserted that many of them had but little concern in the combustion, or vitrification, which follows, when an object is put into that focus. It will therefore not be amiss to mention what gave rise to a surmise, that the power of heating and illuminating objects, might not be equally distributed among the variously coloured rays.

In a variety of experiments I have occasionally made, relating

to the method of viewing the sun, with large telescopes, to the best advantage, I used various combinations of differently-coloured darkening glasses. What appeared remarkable was, that when I used some of them, I felt a sensation of heat, though I had but little light; while others gave me much light, with scarce any sensation of heat. Now, as in these different combinations the sun's image was also differently coloured, it occurred to me, that the prismatic rays might have the power of heating bodies very unequally distributed among them; and, as I judged it right in this respect to entertain a doubt, it appeared equally proper to admit the same with regard to light. If certain colours should be more apt to occasion heat, others might, on the contrary, be more fit for vision, by possessing a superior illuminating power. At all events, it would be proper to recur to experiments for a decision.

Experiments on the heating Power of coloured Rays.

I fixed a piece of pasteboard, AB, (Plate X.) in a frame, mounted upon a stand, CD, and moveable upon two centres. In the pasteboard, I cut an opening, *mn*, a little larger than the ball of a thermometer, and of a sufficient length to let the whole extent of one of the prismatic colours pass through. I then placed three thermometers upon small inclined planes, EF: their balls were blacked with japan ink. That of No. 1 was rather too large for great sensibility. No. 2 and 3 were two excellent thermometers, which my highly esteemed friend Dr. WILSON, late Professor of Astronomy at Glasgow, had lent me for the purpose: their balls being very small, made them of exquisite

sensibility. The scales of all were properly disengaged from the balls.

I now placed the stand, with the framed pasteboard and the thermometers, upon a small plain board, GH; that I might be at liberty to move the whole apparatus together, without deranging the relative situation of the different parts.

This being done, I set a prism, moveable on its axis, into the upper part of an open window, at right angles to the solar ray, and turned it about till its refracted coloured spectrum became stationary, upon a table placed at a proper distance from the window.

The board containing the apparatus was now put on the table, and set in such a manner as to let the rays of one colour pass through the opening in the pasteboard. The moveable frame was then adjusted to be perpendicular to the rays coming from the prism; and the inclined planes carrying the three thermometers, with their balls arranged in a line, were set so near the opening, that any one of them might easily be advanced far enough to receive the irradiation of the colour which passed through the opening, while the rest remained close by, under the shade of the pasteboard.

By repeated trials, I found that Dr. Wilson's No. 2 and mine, always agreed in shewing the temperature of the place where I examined them, when the change was not very sudden; but that mine would require ten minutes to take a change, which the other would shew in five. No. 3 never differed much from No. 2.

1*st Experiment.* Having arranged the three thermometers in the place prepared for the experiment, I waited till they were stationary. Then, advancing No. 1 to the red rays, and leaving

the other two close by, in the shade, I marked down what they shewed, at different times.

No. 1.		No. 2.		No. 3.
$43\frac{1}{2}$	- - -	$43\frac{1}{2}$	- - -	$43\frac{1}{4}$
48	- - -	$43\frac{1}{2}$	- - -	$43\frac{1}{2}$
$49\frac{1}{2}$	- - -	$43\frac{1}{4}$	- - -	$43\frac{1}{4}$
$49\frac{3}{4}$	- - -	$43\frac{1}{4}$	- - -	$43\frac{1}{4}$
50	- - -	$43\frac{1}{4}$	- - -	$43\frac{1}{4}$

This, in about 8 or 10 minutes, gave $6\frac{3}{4}$ degrees, for the rising produced in my thermometer, by the red rays, compared to the two standard thermometers.

2d Experiment. As soon as my thermometer was restored to the temperature of the room, which I hastened, by applying it to a large piece of metal that had been kept in the same place, I exposed it again to the red rays, and registered its march, along with No. 2 as a standard, which was as follows.

No. 1.		No. 2.
45	- - -	45
48	- - -	45
51	- - -	45
51	- - -	$44\frac{1}{2}$
51	- - -	44

Hence, in 10 minutes, the red rays made the thermometer rise 7 degrees.

3d Experiment. Proceeding in the same manner as before, in the green rays I had,

No. 1.				No. 2.
43	-	-	-	43
$45\frac{1}{2}$	-	-	-	43
46	-	-	-	43
46	-	-	-	$42\frac{3}{4}$
46	-	-	-	$42\frac{3}{4}$

Therefore, in ten minutes, the green rays occasioned a rise of $3\frac{1}{4}$ degrees.

4th Experiment. I now exposed my thermometer to the violet rays, and compared it with No. 2.

No. 1.				No. 2.
44	-	-	-	44
44	-	-	-	44
$44\frac{3}{4}$	-	-	-	$43\frac{1}{2}$
45	-	-	-	43

Here we have a rising of 2 degrees, in ten minutes, for the violet rays.

5th Experiment. I now exposed Dr. Wilson's thermometer No. 2 to the red rays, and compared its progress with No. 3.

No. 2.				No. 3.
44	-	-	-	44
46	-	-	-	44
$46\frac{1}{2}$	-	-	-	$43\frac{3}{4}$
$46\frac{1}{2}$	-	-	-	$43\frac{3}{4}$

Here the thermometer, exposed to red, rose in five minutes $2\frac{3}{4}$ degrees.

6th Experiment. In red rays again.

No. 2.				No. 3.
44	-	-	-	44
46	-	-	-	44
$46\frac{1}{2}$	-	-	-	$43\frac{1}{2}$
47	-	-	-	$43\frac{1}{2}$
47	-	-	-	43

And here the thermometer, exposed to red, rose in five minutes 4 degrees.

7th Experiment. In green rays.

No. 2.				No. 3.
$43\frac{1}{2}$	-	-	-	$43\frac{1}{2}$
$44\frac{1}{2}$	-	-	-	$43\frac{1}{2}$
$44\frac{1}{2}$	-	-	-	43

This made the thermometer rise, in the green rays, $1\frac{1}{2}$ degree.

8th Experiment. Again in green rays.

No. 2.				No. 3.
43	-	-	-	43
$44\frac{1}{2}$	-	-	-	$42\frac{3}{4}$
$44\frac{3}{4}$	-	-	-	$42\frac{3}{4}$

Here the rising, by the green rays, was 2 degrees.

From these experiments, we are authorised to draw the following results. In the red rays, my thermometer gave $6\frac{3}{4}$ degrees in the 1st, and 7 degrees in the 2d, for the rising of the quicksilver: a mean of both is $6\frac{7}{8}$. In the 3d experiment, we had $3\frac{1}{4}$ degrees, for the rising occasioned by the green rays; from which we obtain the proportion of 55 to 26, for the power of heating in red to that in green. The 4th experiment gave

2 degrees for the violet rays; and therefore we have the rising of the quicksilver in red to that in violet, as 55 to 16.

A sufficient proof of the accuracy of this determination we have, in the result of the four last experiments. The rising for red rays in the 5th, is $2\frac{3}{4}$; and in the 6th, 4 degrees: a mean of both is $3\frac{3}{8}$. In the 7th experiment, we have $1\frac{1}{2}$, and in the 8th, 2 degrees, for the rising in green: a mean of these is $1\frac{3}{4}$. Therefore, we have the proportion of the rising in red to that in green, as 27 to 11, or as 55 to 22,4.

We may take a mean of the result of both thermometers, which will be 55 to 24,2, or more than $2\frac{1}{4}$ to 1, in red to green; and about $3\frac{1}{2}$ to 1, in red to violet.

It appears remarkable, that the most sensible thermometer should give the least alteration, from the exposure to the coloured rays. But since, in these circumstances, there are two causes constantly acting different ways; the one to raise the thermometer, the other to bring it down to the temperature of the room, I suppose, that on account of the smallness of the ball in Dr. Wilson's No. 1, which is but little more than $\frac{1}{8}$ of an inch, the cooling causes must have a stronger effect on the mercury it contains than they can have on mine, the ball of which is half an inch.

More accuracy may hereafter be obtained, by attending to the circumstances of blacking the balls of the thermometers, and their exposure to a more steady and powerful light of the sun, at greater altitudes than it can be had at present; but the experiments which have been related, are quite sufficient for my present purpose; which only goes to prove, that the heating power of the prismatic colours, is very far from being

equally divided, and that the red rays are chiefly eminent in that respect.

Experiments on the illuminating Power of coloured Rays.

In the following examination of the illuminating power of differently-coloured rays, I had two ends in view. The first was, with regard to the illumination itself; and the next, with respect to the aptness of the rays for giving distinct vision; and, though there did not seem to be any particular reason why these two should not go together, I judged it right to attend to both.

The microscope offered itself as the most convenient instrument for this investigation; and I thought it expedient to view only opaque objects, as these would give me an opportunity to use a direct prismatic ray, without running the risk of any bias that might be given to it, in its transmission through the colouring particles of transparent objects.

1*st Experiment*. I placed an object that had very minute parts, under a double microscope; and, having set a prism in the window, so as to make the coloured image of the sun stationary upon the table where the microscope was placed, I caused the differently-coloured rays to fall successively on the object, by advancing the microscope into their light. The magnifying power was 27 times.

In changing the illumination, by admitting a different colour, it always becomes necessary to re-adjust the instrument. It is well known, that the different refrangibility of the rays will

sensibly affect the focal length of object-glasses; but, in compound vision, such as in a microscope, where a very small lens is made to cast a lengthened secondary focus, this difference becomes still more considerable.

By an attentive and repeated inspection, I found that my object was very well seen in red; better in orange, and still better in yellow; full as well in green; but to less advantage in blue; indifferently well in indigo, and with more imperfection in violet.

This trial was made upon one of the microscopic objects which are generally prepared for transparent vision; but, as I used it in the opaque way, I thought that others might be chosen which would answer the purpose better; and, in order to give some variety to my experiments, and to see the effect differently coloured substances might have on the rays of light, I provided the following materials to be viewed. Red paper; green paper; a piece of brass; a nail; a guinea; black paper. Having also found that a higher power might be used, with sufficient convenience for the rays of light to come from the prism to the object, I made the miscroscope magnify 42 times.

The appearance of the nail in the microscope, is so beautiful, that it deserves to be noticed; and the more so, as it is accompanied with circumstances that are very favourable for an investigation, such as that which is under our present consideration. I had chosen it on account of its solidity and blackness, as being most likely to give an impartial result, of the modifications arising from an illumination by differently-coloured rays; but, on viewing it, I was struck with the sight of a bright constellation of thousands of luminous points, scattered over its whole extent, as far as the field of the microscope could take it in.

Their light was that of the illuminating colour, but differed considerably in brightness; some of the points being dim and faint, while others were luminous and brilliant. The brightest of them also, admitted of a little variation in their colour, or rather in the intensity of the same colour; for, in the centre of some of the most brilliant of these lucid appearances, their light had more vivacity, and seemed to deviate from the illuminating tint towards whiteness, while on and near the circumference, it appeared to take a deeper hue.

An object so well divided by nature, into very minute and differently-arranged points, on which the attention might be fixed, in order to ascertain whether they would be equally distinct in all colours, and whether their number would be increased or diminished by different degrees of illumination, was exactly what I wanted; nor could I think it less remarkable, that all the other objects I had fixed upon, besides many more which have been examined, such as copper, tin, silver, *&c.* presented themselves nearly with the same appearance. In the brass, which had been turned in a lathe, the luminous points were arranged in furrows; and in tin they were remarkably beautiful. The result of the examination of my objects was as follows.

2d Experiment. Red paper.

In the red rays, I view a bright point near an accidental black spot in the paper, which serves me as a mark; and I notice the space between the point and the spot: it contains several faint points.

In the orange rays, I see better. The bright point, I now perceive, is double.

In the yellow rays, I see the object still better.

In the green rays, full as well as before.

In the blue rays, very well.

In the indigo rays, not quite so well as in the blue.

In the violet rays, very imperfectly.

3d Experiment. Green paper.

Red. I fix my attention on many faint points, in a space between two bright double points.

Orange. I see those faint points better.

Yellow. Still better.

Green. As well as before. I see remarkably well.

Blue. Less bright, but very distinct.

Indigo. Not well.

Violet. Bad.

4th Experiment. A piece of very clean turned brass.

R. I remark several faint luminous points between two bright ones. The colour of the brass makes the red rays appear like orange.

O. I see better, but the orange colour is likewise different from what it ought to be; however, this is not, at present, the object of my investigation.

Y. I see still better.

G. I see full as well as before.

B. I do not see so well now.

I. I cannot see well.

V. Bad.

5th Experiment. A nail.

R. I remark two bright points, and some faint ones.

O. Brighter than before; and more points visible. Very distinct.

Y. Much brighter than before; and more points and lines visible. Very distinct.

G. Full as bright; and as many points visible. Very distinct.

B. Much less bright. Very distinct.

I. Still less bright. Very distinct.

V. Much less bright again. Very distinct.

6th Experiment. I viewed a guinea, at 9 feet 6 inches from the prism; and adjusted the place of the object in the several rays, by the shadow of the guinea. If this be not done, deceptions will take place.

R. Four remarkable points. Very distinct.

O. Better illuminated. Very distinct.

Y. Still better illuminated. Very distinct. The points all over the field of view are coloured; some green; some red; some yellow; and some white, encircled with black about them.

Between yellow and green is the maximum of illumination. Extremely distinct.

G. As well illuminated as the yellow. Very distinct.

B. Much inferior in illumination. Very distinct.

I. Badly illuminated. Distinct.

V. Very badly illuminated. I can hardly see the object at all.

7th Experiment. The nail again, at 8 feet from the prism.

R. I attended to two bright points, with faint ones between them. Almost all the points in the field of view are red. Very distinct.

O. I see all the points better: they are red, green, yellow, and whitish, with black about them. Very distinct.

Y. I see better. More bright points, and more faint ones: the points are of various colours. Very distinct.

G. I see as well. The points are mostly green, and brightish-green, inclining to white. Very distinct.

B. Much worse illuminated. Very distinct.

I. Badly illuminated. Very distinct.

V. There is hardly any illumination.

8th Experiment. The nail again, at 9 feet 6 inches from the prism, by way of having the rays better separated.

R. Badly illuminated. The bright points are very distinct.

O. Much better illuminated. The bright points very distinct.

Y. Still better illuminated. All points extremely distinct.

G. As well illuminated, and equally distinct.

B. Badly illuminated. The bright points are distinct; but the others are not so.

I. Very badly illuminated. I do not see distinctly; but I believe it to be for want of light.

V. So badly illuminated that I cannot see the object; or at least but barely perceive that it exists.

9th Experiment. Black paper, at 8 feet from the prism.

R. The object is hardly visible. I can only see a few faint points.

O. I see several bright points, and many faint ones.

Y. Numberless bright and small faint points.

Between yellow and green, is the maximum of illumination.

G. The same as the yellow.

B. Very indifferently illuminated; but not so bad as in the red rays.

I. I cannot see the object.

V. Totally invisible.

From these observations, which agree uncommonly well, with respect to the illuminating power assigned to each colour, we may conclude, that the red-making rays are very far from having it in any eminent degree. The orange possess more of it than the red; and the yellow rays illuminate objects still more

perfectly. The maximum of illumination lies in the brightest yellow, or palest green. The green itself is nearly equally bright with the yellow; but, from the full deep green, the illuminating power decreases very sensibly. That of the blue is nearly upon a par with that of the red; the indigo has much less than the blue; and the violet is very deficient.

With regard to the principle of distinctness, there appears to be no deficiency in any one of the colours. In the violet rays, for instance, some of the experiments mention that I saw badly; but this is to be understood only with respect to the number of small objects that could be perceived; for, although I saw fewer of the points, those which remained visible were always as distinct as, in so feeble an illumination, could be expected. It must indeed be evident, that by removing the great obstacle to distinct vision, which is, the different refrangibility of the rays of light, a microscope will be capable of a much higher degree of distinctness than it can be under the usual circumstances. A celebrated optical writer has formerly remarked, that a fly, illuminated by red rays, appeared uncommonly distinct, and that all its minute parts might be seen in great perfection; and, from the experiments which have been related, it appears that every other colour is possessed of the same advantage.

I am well aware that the results I have drawn from the foregoing experiments, both with regard to the heating and illuminating powers of differently-coloured rays, must be affected by some little inaccuracies. The prism, under the circumstances in which I have used it, could not effect a complete separation of the colours, on account of the apparent diameter of the sun, and the considerable breadth of the prism itself, through which the rays were transmitted.

Perhaps an arrangement like that in Fig. 16, of the NEWTONIAN experiments, might be employed; if instruments of sufficient sensibility, such as air thermometers, can be procured, that may be affected by the enfeebled illumination of rays that have undergone four transmissions, and eight refractions; and especially when their incipient quantity has been so greatly reduced, in their limited passage through a small hole at the first incidence.

But it appeared most expedient for me, at present, to neglect all further refinements, which may be attempted hereafter at leisure. It may even be presumed that, had there not been some small admixture of the red rays in the other colours, the result would have been still more decisive, with regard to the power of heating vested in the red rays. And it is likewise evident, that at least the red light of the prismatic spectrum, was much less adulterated than any of the other colours; their refractions tending all to throw them from the red. That the same rays which occasion the greatest heat, have not the power of illumination in any strong degree, stands on as good a foundation. For, since here also they have undergone the fairest trial, as being most free from other colours, it is equally proved that they illuminate objects but imperfectly. There is some probability that a ray, purified in the NEWTONIAN manner above quoted, especially in a well darkened room, may remain bright enough to serve the purpose of microscopic illumination, in which case, more precision can easily be obtained.

The greatest cause for a mixture of colours, however, which is, the breadth of the prism, I saw might easily be removed; therefore, on account of the coloured points, which have been mentioned in the 6th and 7th experiments, I was willing to try

whether they proceeded from this mixture; and therefore covered the prism in front with a piece of pasteboard, having a slit in it of about $\frac{1}{10}$ of an inch broad.

10*th Experiment.* The nail, at 9 feet 2 inches from the prism.

R. I fix my attention on two shining, red points; they are pretty bright.

O. I see many more points. The object is better illuminated than in the red. The points are surrounded by black; but are orange-coloured.

Y. The points now are yellow, and white surrounded by black. The object is better illuminated than in orange.

The maximum of illumination is in the brightest yellow, or palest green.

G. The points are green and white, as before surrounded by black. Better illuminated than in orange.

B. The illumination is nearly equal to red.

I. Very indifferently illuminated.

V. Very badly illuminated.

The phænomena of the differently-coloured points being now completely resolved, since they were plainly owing to the former admixture of colours, and the illuminating power remaining ascertained as before, I attempted also to repeat the experiments upon the thermometer, with the prism covered in the same manner; but I found the effect of the coloured rays too much enfeebled to give a decisive result.

I might now proceed to my next subject; but it may be pardonable if I digress for a moment, and remark, that the foregoing researches ought to lead us on to others. May not the chemical properties of the prismatic colours be as different as those which relate to light and heat? Adequate methods for an investigation

of them may easily be found; and we cannot too minutely enter into an analysis of light, which is the most subtle of all the active principles that are concerned in the mechanism of the operations of nature. A better acquaintance with it may enable us to account for various facts that fall under our daily observation, but which have hitherto remained unexplained. If the power of heating, as we now see, be chiefly lodged in the red-making rays, it accounts for the comfortable warmth that is thrown out from a fire, when it is in the state of a red glow; and for the heat which is given by charcoal, coke, and balls of small-coal mixed up with clay, used in hot-houses; all which, it is well known, throw out red light. It also explains the reason why the yellow, green, blue, and purple flames of burning spirits mixed with salt, occasion so little heat that a hand is not materially injured, when passed through their coruscations. If the chemical properties of colours also, when ascertained, should be such that an acid principle, for instance, which has been ascribed to light in general, on account of its changing the complexion of various substances exposed to it, may reside only in one of the colours, while others may prove to be differently invested, it will follow, that bodies may be variously affected by light, according as they imbibe and retain, or transmit and reflect, the different colours of which it is composed.

Radiant Heat is of different Refrangibility.

I must now remark, that my foregoing experiments ascertain beyond a doubt, that radiant heat, as well as light, whether they be the same or different agents, is not only refrangible,

but is also subject to the laws of the dispersion arising from its different refrangibility; and, as this subject is new, I may be permitted to dwell a few moments upon it. The prism refracts radiant heat, so as to separate that which is less efficacious, from that which is more so. The whole quantity of radiant heat contained in a sun-beam, if this different refrangibility did not exist, must inevitably fall uniformly on a space equal to the area of the prism; and, if radiant heat were not refrangible at all, it would fall upon an equal space, in the place where the shadow of the prism, when covered, may be seen. But, neither of these events taking place, it is evident that radiant heat is subject to the laws of refraction, and also to those of the different refrangibility of light. May not this lead us to surmise, that radiant heat consists of particles of light of a certain range of momenta, and which range may extend a little farther, on each side of refrangibility, than that of light? We have shewn, that in a gradual exposure of the thermometer to the rays of the prismatic spectrum, beginning from the violet, we come to the maximum of light, long before we come to that of heat, which lies at the other extreme. By several experiments, which time will not allow me now to report, it appears that the maximum of illumination has little more than half the heat of the full red rays; and, from other experiments, I likewise conclude, that the full red falls still short of the maximum of heat; which perhaps lies even a little beyond visible refraction. In this case, radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum as to be unfit for vision. And, admitting, as is highly probable, that the organs of sight are only adapted to receive impressions from

particles of a certain momentum, it explains why the maximum of illumination should be in the middle of the refrangible rays; as those which have greater or less momenta, are likely to become equally unfit for impressions of sight. Whereas, in radiant heat, there may be no such limitation to the momentum of its particles. From the powerful effects of a burning lens, however, we gather the information, that the momentum of terrestrial radiant heat is not likely to exceed that of the sun; and that, consequently, the refrangibility of *calorific* rays cannot extend much beyond that of *colourific* light. Hence we may also infer, that the invisible heat of red-hot iron, gradually cooled till it ceases to shine, has the momentum of the invisible rays which, in the solar spectrum viewed by day-light, go to the confines of red; and this will afford an easy solution of the reflection of invisible heat by concave mirrors.

Application of the Result of the foregoing Observations, to the Method of viewing the Sun advantageously, with Telescopes of large Apertures and high magnifying Powers.

Some time before the late transit of Mercury over the disk of the sun, I prepared my 7-feet telescope, in order to see it to the best advantage. As I wished to keep the whole aperture of the mirror open, I soon cracked every one of the darkening slips of wedged glasses, which are generally used with achromatic telescopes: none of them could withstand the accumulated heat in the focus of pencils, where these glasses are generally placed. Being thus left without resource, I made use of red glasses; but was by no means satisfied with their performance.

My not being better prepared, as it happened, was of no consequence; the weather proving totally unfavourable for viewing the sun at the time of the transit. However, as I was fully aware of the necessity of providing an apparatus for this purpose, since no method that was in use could be applied to my telescopes, I took the first opportunity of beginning my trials.

The instrument I wished to adapt for solar inspection, was a NEWTONIAN reflector, with 9 inches aperture; and my aim was, to use the whole of it open.

I began with a red glass; and, not finding it to stop light enough, took two of them together. These intercepted full as much light as was necessary; but I soon found that the eye could not bear the irritation, from a sensation of heat, which it appeared these glasses did not stop.

I now took two green glasses; but found that they did not intercept light enough. I therefore smoked one of them; and it appeared that, notwithstanding they now still transmitted considerably more light than the red glasses, they remedied the former inconvenience of an irritation arising from heat. Repeating these trials several times, I constantly found the same result; and, the sun in the first case being of a deep red colour, I surmised that the red-making rays, transmitted through red glasses, were more efficacious in raising a sensation of heat, than those which passed through green, and which caused the sun to look greenish. In consequence of this surmise, I undertook the investigations which have been delivered under the two first heads.

As soon as I was convinced that the red light of the sun ought to be intercepted, on account of the heat it occasions, and that it might also be safely set aside, since it was now proved

that pale green light excels in illumination, the method which ought to be pursued in the construction of a darkening apparatus was sufficiently pointed out; and nothing remained but to find such materials as would give us the colour of the sun, viewed in a telescope, of a pale green light, sufficiently tempered for the eye to bear its lustre.

To determine what glasses would most effectually stop the red rays, I procured some of all colours, and tried them in the following manner.

I placed a prism in the upper part of a window, and received its coloured spectrum upon a sheet of white paper. Then I intercepted the colours, just before they came to the paper, successively, by the glasses, and found the result as follows.

A deep red glass intercepted all the rays.

A paler red did the same.

From this, we ought not to conclude that red glasses will stop the red rays; but rather, that none of the sun's light, after its dispersion by the prism, remains intense enough to pass through red glasses, in sufficient quantity to be perceptible, when it comes to the paper. By looking through them directly at the sun, or even at day objects, it is sufficiently evident that they transmit chiefly red rays.

An orange glass transmitted nearly all the red, the orange, and the yellow. It intercepted some of the green; much of the blue; and very little of the indigo and violet.

A yellow glass intercepted hardly any light, of any one of the colours.

A dark green glass intercepted nearly all the red, and partly also the orange and yellow. It transmitted the green; intercepted much of the blue; but none of the indigo and violet.

A darker green glass intercepted nearly all the red; much of the orange; and a little of the yellow. It transmitted the green; stopped some of the blue; but transmitted the indigo and violet.

A blue glass intercepted much of the red and orange; some of the yellow; hardly any of the green; none of the blue, indigo, or violet.

A purple glass transmitted some of the red; a very little of the orange and yellow: it also transmitted a little of the green and blue; but more of the indigo and violet.

From these experiments we see, that dark green glasses are most efficacious for intercepting red light, and will therefore answer one of the intended purposes; but since, in viewing the sun, we have also its splendour to contend with, I proceeded to the following additional trials.

White glass, lightly smoked, apparently intercepted an equal share of all the colours; and, when the smoke was laid on thicker, it permitted none of them to pass.

Hard pitch, melted between two white glasses, intercepted much light; and, when put on sufficiently thick, transmitted none.

Many differently-coloured fluids, that were also tried, I found were not sufficiently pure to be used, when dense enough to stop light.

Now, red glasses, and the two last-mentioned resources of smoke, and pitch, any one of which, it has been seen, will stop as much light as may be required, had still a remaining trial to undergo, relating to distinctness; but this I was convinced could only be decided by actual observations of the sun.

As an easy way of smoking glasses uniformly is of some

consequence to distinct vision, it may be of service here to give the proper directions, how to proceed in the operation.

With a pair of warm pliers, take hold of the glass, and place it over a candle, at a sufficient distance not to contract smoke. When it is heated, but no more than still to permit a finger to touch the edges of it, bring down the glass, at the side of the flame, as low as the wick will permit, which must not be touched. Then, with a quick vibratory motion, agitate it in the flame from side to side; at the same time advancing and retiring it gently all the while. By this method, you may proceed to lay on smoke to any required darkness. It ought to be viewed from time to time, not only to see whether it be sufficiently dark, but whether any inequality may be perceived; for, if that should happen, it will not be proper to go on.

The smoke of sealing-wax is bad: that of pitch is worse. A wax candle gives a good smoke; but that of a tallow candle is better. As good as any I have hitherto met with, is the smoke of spermaceti oil. In using a lamp, you may also have the advantage of an even flame extended to any length.

Telescopic Experiments.

No. 1. By way of putting my theory to the trial, I used two red glasses, and found that the heat which passed through them could not be suffered a moment; but I was now also convinced that distinctness of vision is capitally injured, by the colouring matter of these glasses.

No. 2. I smoked a white glass, till it stopped light enough to

permit the eye to bear the sun. This destroyed all distinctness; and also permitted some heat to come to the eye, by transmitting chiefly red rays.

No. 3. I applied two white glasses, with pitch between them, to the telescope; and found that it made the sun appear of a scarlet colour. They transmitted some heat; and distinctness was greatly injured.

No 4. I used a very dark green glass, to stop heat; and behind it, or towards the eye, I placed a red glass, to stop light. The first glimpse I had of the sun, was accompanied with a sensation of heat; distinctness also was materially injured.

No. 5. I used a dark green and a pale red; but, the sun not being sufficiently darkened, I smoked the red glass, and, putting a small partition between the two, placed the smoke towards the green glass. This took off the exuberance of light; but did not remedy the inconvenience arising from heat.

No. 6. I used two pale green glasses; smoking that next to the eye, and placing it as in No. 5, so that the smoke might be inclosed between the two. This acted incomparably well; but, in a very short time, the heat which passed the first glass, (though not the second, for I felt no sensation of it in the eye,) disordered the smoke, by drawing it up into little blisters or stars, which let through light; and this composition, therefore, soon became useless.

No. 7. I used two dark green glasses, one of them smoked, as in No. 5. These also acted well; but became useless, for the reason assigned in No. 6, though somewhat less smoke had been required than in the former composition. I felt no heat.

No. 8. I used one pale green, with a dark green smoked glass upon it, as in No. 5. It bore an aperture of 4 inches very

well, and the smoke was not disordered; but, when all the tube was open, the pale green glass cracked in a few minutes.

No. 9. Placing now a dark green before a smoked green, I saw the sun remarkably well. In this experiment, I had made a difference in the arrangement of the apparatus. The cracking of the glasses, I supposed, might be owing to their receiving heat in the middle, while the outside remained cold; which would occasion a partial dilatation. I therefore cut them into pieces about a quarter of an inch square, and set three of them in a slider, so that I could move them behind the smoked glass, without disturbing it. After looking about three or four minutes through one of them, I moved the slider to the second, and then to the third. This kept the glasses sufficiently cool; but the disturbance of the alterations proved hurtful to vision, which requires repose; and, if perchance I stopped a little longer than the proper time, the glass cracked, with a very disagreeable explosion, that endangered the eye.

No. 10. Two dark green glasses, both smoked, that a thinner coat might be on each; but the smoke still contracted blisters, though less dense than before.

No. 11. To get rid of smoke intirely, I used two dark green glasses, two very dark green, two pale blue, and one pale green glass, together. Distinctness was wanting; nor was light sufficiently intercepted.

No. 12. A dark green and a pale blue glass, smoked. The green glass cracked.

No. 13. A pale blue and a dark green glass, smoked. The blue glass cracked. The eye felt no sensation of heat.

No. 14. Two pale blue glasses, one smoked. The first glass cracked.

It was now sufficiently evident, that no glass which stops heat, and therefore receives it, could be preserved from cracking, when exposed to the focus of pencils. This induced me to try an application of the darkening apparatus to another part of the telescope.

The place where the rays are least condensed, without interfering with the reflections of the mirrors, is immediately close to the small one. I therefore screwed an apparatus to the speculum arm, into which any glass might be placed.

No. 15. A dark green glass close to the small speculum, and smoked pale green in the focus of pencils, as before. I saw remarkably well.

No. 16. The dark green as before; but, that more light might be admitted, a white smoked glass near the eye. Better than No. 15; but the green glass cracked.

No. 17. A very dark green and white smoked glass, as before. Very distinct, but the green glass cracked in about six or seven minutes.

No. 18. A dark blue glass, as in No. 15, and white smoked. This was distinct; and no heat came to the eye. The sun appeared ruddy.

No. 19. A dark blue and a yellow glass, close together, as in No. 15, and a white smoked one, as before. This was not distinct.

No. 20. A purple glass, as in No. 15, with a white smoked one. This gave the sun of a deep orange colour, approaching to scarlet. It was not distinct.

No. 21. An orange glass, as in No. 15, with a white smoked one. The colour of the sun was too red.

No. 22. A white smoked glass, as in No. 15, without any

other at the eye. This gave the sun of a beautiful orange colour; but distinctness was totally destroyed.

No. 23. The heat near the small speculum being still too powerful for the glasses, I had a bluish dark green glass made of a proper diameter to be inclosed between the two eye-glasses of a double eye-piece. All glass I knew would stop some heat; and was therefore in hopes that the interposition of this eye-glass would temper the rays, so as in some measure to protect the coloured glass. In the usual place near the eye, I put two white glasses, with a thin coat of pitch between them. These glasses, when looked through by the natural eye, give the sun of a red colour; I therefore entertained no great hopes of their application to the telescope. They darkened the sun not sufficiently; and, when the pitch was thickened, distinctness was wanting.

No. 24. The same glass between the eye-glasses, and a dark green smoked glass at the eye. Very distinct. This arrangement is preferable to that of No. 15; after some considerable time, however, this glass also cracked.

No. 25. I placed a very dark green glass behind the second eye-glass, that it might be sheltered by both glasses, which in my double eye-piece are close together, and of an equal focal length. Here, as the rays are not much concentrated, the coloured glass receives them on a large surface, and stops light and heat, in the proportion of the squares of its diameter now used, to that on which the rays would have fallen, had it been placed in the focus of pencils. And, for the same reason, I now also placed a dark green smoked glass close upon the former, with the smoked side towards the eye, that the smoke might

likewise be protected against heat, by a passage of the rays through two surfaces of coloured glass.

This position had moreover the advantage of leaving the telescope, with its mirrors and glasses, completely to perform its operation, before the application of the darkening apparatus; and thus to prevent the injury which must be occasioned, by the interposition of the heterogeneous colouring matter of the glasses and of the smoke.

No. 26. I placed a deep blue glass with a bluish green smoked one upon it, as in No. 25, and found the sun of a whiter colour than with the former composition. There was no disagreeable sensation of heat; though a little warmth might be felt.

No. 27. I used two black glasses, placed as in No. 25. Here there was no occasion for smoke; but the sun appeared of a bright scarlet colour, and an intolerable sensation of heat took place immediately. I rather suspect that these are very deep red glasses, though their outward appearance is black.

In order to have a more sure criterion of heat, I applied Dr. WILSON's thermometer, No. 2, to the end of the eye-piece, where the eye is generally placed. With No. 25, it rose from 34 to 37 degrees. With No. 26, it rose from 35 to 46; and, with No. 27, it rose, very quickly, from 36 to 95 degrees. I am pretty sure it would have mounted up still higher; but, the scale extending only to 100, I was not willing to run the risk of breaking the thermometer by a longer exposure.

It remains now only to be added, that with No. 25 and 26 I have seen uncommonly well; and that, in a long series of very interesting observations upon the sun, which will soon be

communicated, the glasses have met with no accident. However, when the sun is at a considerable altitude, it will be advisable to lessen the aperture a little, in telescopes that have so much light as my 10-feet reflector; or, which will give us more distinctness, to view the sun earlier in the morning, and later in the afternoon; for, the light intercepted by the atmosphere in lower altitudes, will reduce its brilliancy much more uniformly than we can soften it, by laying on more smoke upon our darkening glasses. Now, as few instruments in common use are so large as that to which this method of darkening has been adapted, we may hope that it will be of general utility in solar observations.

Slough, near Windsor,
March 8, 1800.

№ 46

EXPERIMENTS

ON THE

REFRANGIBILITY OF THE INVISIBLE RAYS OF THE SUN.

Read before the ROYAL SOCIETY, *April* 24, 1800.

In that section of my former paper which treats of radiant heat, it was hinted, though from imperfect experiments, that the range of its refrangibility is probably more extensive than that of the prismatic colours; but, having lately had some favourable sunshine, and obtained a sufficient confirmation of the same, it will be proper to add the following experiments to those which have been given.

I provided a small stand, with four short legs, and covered it with white paper.* On this I drew five lines, parallel to one end of the stand, at half an inch distance from each other, but so that the first of the lines might only be $\frac{1}{4}$ of an inch from the edge. These lines I intersected at right angles with three others; the 2d and 3d whereof were, respectively, at $2\frac{1}{2}$ and at 4 inches from the first.

The same thermometers that have before been marked No. 1, 2, and 3, mounted upon their small inclined planes, were then placed so as to have the centres of the shadow of their balls thrown on the intersection of these lines. Now, setting

* See Plate XI.

my little stand upon a table, I caused the prismatic spectrum to fall with its extreme colour upon the edge of the paper, so that none might advance beyond the first line. In this arrangement, all the spectrum, except the vanishing last quarter of an inch, which served as a direction, passed down by the edge of the stand, and could not interfere with the experiments. I had also now used the precaution of darkening the window in which the prism was placed, by fixing up a thick dark green curtain, to keep out as much light as convenient.

The thermometers being perfectly settled at the temperature of the room, I placed the stand so that part of the red colour, refracted by the prism, fell on the edge of the paper, before the thermometer No. 1, and about half way, or 1¼ inch, towards the second: it consequently did not come before that, or the 3d thermometer, both which were to be my standards. During the experiment, I kept the last termination of visible red carefully to the first line, as a limit assigned to it, by gently moving the stand when required; and found the thermometers, which were all placed on the second line, affected as follows.

No. 1.			No. 2.			No. 3.
45	-	-	45	-	-	44
49	-	-	45	-	-	44
51	-	-	44¼	-	-	44
50¼	-	-	43¼	-	-	43½

Here the thermometer No. 1 rose 6½ degrees, in 10 minutes, when its centre was placed ½ inch beyond visible light.

In order to have a confirmation of this fact, I cooled the thermometer No. 1, and placed No. 2 in the room of it: I also put No. 3 in the place of No. 2, and No. 1 in that of No. 3;

and, having exposed them as before, arranged on the second line, I had the following result.

No. 2.			No. 3.			No. 1.
44	-	-	44	-	-	45
47	-	-	44	-	-	45
$46\frac{1}{4}$	-	-	44	-	-	45
$46\frac{1}{4}$	-	-	44	-	-	45

Here the thermometer No. 2 rose $2\frac{1}{4}$ degrees, in 12 minutes; and being, as has been noticed before, much more sensible than No. 1, it came to the temperature of its situation in a short time; but I left it exposed longer, on purpose to be perfectly assured of the result. Its shewing but $2\frac{1}{4}$ degrees advance, when No. 1 shewed $6\frac{1}{2}$, has also been accounted for before.

It being now evident that there was a refraction of rays coming from the sun, which, though not fit for vision, were yet highly invested with a power of occasioning heat, I proceeded to examine its extent as follows.

The thermometers were arranged on the third line, instead of the second; and the stand was, as before, immersed up to the first, in the coloured margin of the vanishing red rays. The result was thus.

No. 1.			No. 2.			No. 3.
46	-	-	46	-	-	$45\frac{3}{4}$
50	-	-	$46\frac{1}{2}$	-	-	46
$51\frac{3}{4}$	-	-	$46\frac{3}{4}$	-	-	$46\frac{1}{4}$
$52\frac{1}{4}$	-	-	47	-	-	$46\frac{1}{4}$

Here the thermometer No. 1 rose $5\frac{1}{4}$ degrees, in 13 minutes, at 1 inch behind the visible light of the red rays.

I placed now the thermometers on the 4th line, instead of the 3d; and, proceeding as before, I had the following result.

No. 1.			No. 2.			No. 3.
$48\frac{1}{4}$	-	-	$48\frac{1}{4}$	-	-	$47\frac{3}{4}$
$51\frac{1}{2}$	-	-	$48\frac{3}{8}$	-	-	$47\frac{7}{8}$

Therefore, the thermometer No. 1 rose $3\frac{1}{8}$ degree, in 10 minutes, at $1\frac{1}{2}$ inch beyond the visible light of the red rays.

I might now have gone on to the 5th line; but, so fine a day, with regard to clearness of sky and perfect calmness, was not to be expected often, at this time of the year; I therefore hastened to make a trial of the other extreme of the prismatic spectrum. This was attended with some difficulty, as the illumination of the violet rays is so feeble, that a precise termination of it cannot be perceived. However, as well as could be judged, I placed the thermometers one inch beyond the reach of the violet rays, and found the result as follows,

No. 1.			No. 2.			No. 3.
48	-	-	48	-	-	$47\frac{3}{4}$
48	-	-	48	-	-	$47\frac{3}{4}$
48	-	-	$47\frac{1}{2}$	-	-	47
$48\frac{1}{2}$	-	-	$47\frac{1}{2}$	-	-	47
48	-	-	48	-	-	$47\frac{3}{4}$

Here the several indications of the thermometers, two of which, No. 1 and 2, were used as variable, while the 3d was kept as the standard, were read off during a time that lasted 12 minutes; but they afford, as may be seen by inspection, no ground for ascribing any of their small changes to other causes than the accidental disturbance which will arise from the motion of the air, in a room where some employment is carried on.

I exposed the thermometer now to the line of the very first perceptible violet light; but so that No. 1 and 2 might again

be in the illumination, while No. 3 remained a standard. The result proved as follows.

No. 1.			No. 2.			No. 3.
48	-	-	48	-	-	47¾
48½	-	-	48	-	-	47¾
48¾	-	-	48½	-	-	47¾
49	-	-	48½	-	-	47¾

Here the thermometer No. 1 rose 1 degree, in 15 minutes; and No. 2 rose ½ degree, in the same time.

From these last experiments, I was now sufficiently persuaded, that no rays which might fall beyond the violet, could have any perceptible power, either of illuminating or of heating; and that both these powers continued together throughout the prismatic spectrum, and ended where the faintest violet vanishes.

A very material point remained still to be determined, which was, the situation of the maximum of the heating power.

As I knew already that it did not lie on the violet side of the red, I began at the full red colour, and exposed my thermometers, arranged on a line, so as to have the ball of No. 1 in the midst of its rays, while the other two remained at the side, unaffected by them.

No. 1.			No. 2.			No. 3.
48½	-	-	48½			48
55½		-	48½	-	-	48
55½		-	48½	-	-	48

Here the thermometer No. 1 rose 7 degrees, in 10 minutes, by an exposure to the full red coloured rays.

I drew back the stand, till the centre of the ball of No. 1 was

just at the vanishing of the red colour, so that half its ball was within, and half without, the visible rays of the sun.

No. 1.			No. 2.			No. 3.
$48\frac{1}{2}$	-	-	$48\frac{1}{2}$	-	-	48
$55\frac{1}{2}$	-	-	$48\frac{1}{2}$	-	-	48
57	-	-	49	-	-	$48\frac{1}{2}$

Here the thermometer No. 1 rose 8 degrees, in 10 minutes.

By way of not losing time, in order to connect these last observations the better together, I did not bring back the thermometer No. 1 to the temperature of the room, being already well acquainted with its rate of shewing, compared to that of No. 2, but went on to the next experiment, by withdrawing the stand, till the whole ball of No. 1 was completely out of the sun's visible rays, yet so as to bring the termination of the line of the red colour as near the outside of the ball as could be, without touching it.

No. 1.			No. 2.			No. 3.
57	-	-	49	-	-	$48\frac{1}{2}$
$58\frac{1}{2}$	-	-	$49\frac{1}{4}$	-	-	49
59	-	-	$50\frac{1}{4}$	-	-	$49\frac{1}{4}$
59	-	-	50	-	-	$49\frac{1}{2}$

Here the thermometer No. 1 rose, in 10 minutes, another degree higher than in its former situation it could be brought up to; and was now 9 degrees above the standard. The ball of this thermometer, as has been noticed, is exactly half an inch in diameter; and its centre therefore was $\frac{1}{4}$ inch beyond the visible illumination, to which no part of it was exposed.

It would not have been proper to compare these last observations with those taken at an earlier period this morning, in

order to obtain a true maximum, as the sun was now more powerful than it had been at that time; for which reason, I caused the line of termination of visible light, now to fall again just $\frac{1}{2}$ inch from the centre of the ball; and had the following result.

No. 1.		No. 2.		No. 3.
$50\frac{1}{2}$	- -	$50\frac{1}{2}$	- -	50
$57\frac{3}{4}$	- -	50	- -	$49\frac{1}{2}$
$58\frac{1}{2}$	- -	50	- -	$49\frac{1}{2}$
$58\frac{3}{4}$	- -	50	- -	$49\frac{1}{2}$

And here the thermometer No. 1 rose, in 16 minutes, $8\frac{3}{4}$ degrees, when its centre was $\frac{1}{2}$ inch out of the visible rays of the sun. Now, as before we had a rising of 9 degrees, and here $8\frac{3}{4}$, the difference is almost too trifling to suppose, that this latter situation of the thermometer was much beyond the maximum of the heating power; while, at the same time, the experiment sufficiently indicates, that the place inquired after need not be looked for at a greater distance.

It will now be easy to draw the result of these observations into a very narrow compass.

The first four experiments prove, that there are rays coming from the sun, which are less refrangible than any of those that affect the sight. They are invested with a high power of heating bodies, but with none of illuminating objects; and this explains the reason why they have hitherto escaped unnoticed.

My present intention is, not to assign the angle of the least refrangibility belonging to these rays, for which purpose more accurate, repeated, and extended experiments are required. But, at the distance of 52 inches from the prism, there was still a considerable heating power exerted by our invisible rays, one

inch and a half beyond the red ones, measured upon their projection on a horizontal plane. I have no doubt but that their efficacy may be traced still somewhat farther.

The 5th and 6th experiments shew, that the power of heating is extended to the utmost limits of the visible violet rays, but not beyond them; and that it is gradually impaired, as the rays grow more refrangible.

The four last experiments prove, that the maximum of the heating power is vested among the invisible rays; and is probably not less than half an inch beyond the last visible ones, when projected in the manner before mentioned. The same experiments also shew, that the sun's invisible rays, in their less refrangible state, and considerably beyond the maximum, still exert a heating power fully equal to that of red-coloured light; and that, consequently, if we may infer the quantity of the efficient from the effect produced, the invisible rays of the sun probably far exceed the visible ones in number.

To conclude, if we call *light*, those rays which illuminate objects, and *radiant heat*, those which heat bodies, it may be inquired, whether light be essentially different from radiant heat? In answer to which I would suggest, that we are not allowed, by the rules of philosophizing, to admit two different causes to explain certain effects, if they may be accounted for by one. A beam of radiant heat, emanating from the sun, consists of rays that are differently refrangible. The range of their extent, when dispersed by a prism, begins at violet-coloured light, where they are most refracted, and have the least efficacy. We have traced these calorific rays throughout the whole extent of the prismatic spectrum; and found their power increasing, while their refrangibility was lessened, as far

as to the confines of red-coloured light. But their diminishing refrangibility, and increasing power, did not stop here; for we have pursued them a considerable way beyond the *prismatic spectrum,* into an invisible state, still exerting their increasing energy, with a decrease of refrangibility up to the maximum of their power; and have also traced them to that state where, though still less refracted, their energy, on account, we may suppose, of their now failing density, decreased pretty fast; after which, the invisible *thermometrical spectrum,* if I may so call it, soon vanished.

If this be a true account of solar heat, for the support of which I appeal to my experiments, it remains only for us to admit, that such of the rays of the sun as have the refrangibility of those which are contained in the prismatic spectrum, by the construction of the organs of sight, are admitted, under the appearance of light and colours; and that the rest, being stopped in the coats and humours of the eye, act upon them, as they are known to do upon all the other parts of our body, by occasioning a sensation of heat.

Slough, near Windsor,
March 17, 1800.

EXPLANATION OF PLATE XI.

IN WHICH IS GIVEN A VIEW OF THE APPARATUS.

A B. The small stand.

1, 2, 3. The thermometers upon it.

C D. The prism at the window.

E. The spectrum thrown upon the table, so as to bring the last quarter of an inch of the red colour upon the stand.

No. 47.

EXPERIMENTS
ON
THE SOLAR, AND ON THE TERRESTRIAL RAYS
THAT OCCASION HEAT.

PART I.

Read before the ROYAL SOCIETY, *May* 15, 1800.

THE word heat, in its most common acceptation, denotes a certain sensation, which is well known to every person. The cause of this sensation, to avoid ambiguity, ought to have been distinguished by a name different from that which is used to point out its effect. Various authors indeed, who have treated on the subject of heat, have occasionally added certain terms to distinguish their conceptions, such as, latent, absolute, specific, sensible heat; while others have adopted the new expressions of caloric, and the matter of heat. None of these descriptive appellations however would have completely answered my purpose. I might, as in the preceding papers, have used the name radiant heat, which has been introduced by a celebrated author, and which certainly is not very different from the expressions I have now adopted; but, by calling the subject of my researches, the rays that occasion heat, I cannot be misunderstood as meaning that these rays themselves are heat; nor do I in any respect engage myself to shew in what manner they produce heat.

From what has been said it follows, that any objections that may be alleged, from the supposed agency of heat in other

circumstances than in its state of radiance, or heat-making rays, cannot be admitted against my experiments. For, notwithstanding I may be inclined to believe that all phænomena in which heat is concerned, such as the expansion of bodies, fluidity, congelation, fermentation, friction, *&c.* as well as heat in its various states of being latent, specific, absolute, or sensible, may be explained on the principle of heat-making rays, and vibrations occasioned by them in the parts of bodies; yet this is not intended, at present, to be any part of what I shall endeavour to establish.

I must also remark, that in using the word rays, I do not mean to oppose, much less to countenance, the opinion of those philosophers who still believe that light itself comes to us from the sun, not by rays, but by the supposed vibrations of an elastic ether, every where diffused throughout space; I only claim the same privilege for the rays that occasion heat, which they are willing to allow to those that illuminate objects. For, in what manner soever this radiance may be effected, it will be fully proved hereafter, that the evidence, either for rays, or for vibrations which occasion heat, stands on the same foundation on which the radiance of the illuminating principle, light, is built.

In order to enter on our subject with some regularity, it will be necessary to distinguish heat into six different kinds, three whereof are solar, and three terrestrial; but, as the divisions of terrestrial heat strictly resemble those of solar, it will not be necessary to treat of them separately; our subject, therefore, may be reduced to the three following general heads.

We shall begin with the heat of luminous bodies in general, such as, in the first place, we have it directly from the sun;

and as, in the second, we may obtain it from terrestrial flames, such as torches, candles, lamps, blue-lights, *&c.*

Our next division comprehends the heat of coloured radiants. This we obtain, in the first place, from the sun, by separating its rays in a prism; and, in the second, by having recourse to culinary fires, openly exposed.

The third division relates to heat obtained from radiants, where neither light nor colour in the rays can be perceived. This, as I have shewn, is to be had, in the first place, directly from the sun, by means of a prism applied to its rays; and, in the second, we may have it from fires inclosed in stoves, and from red-hot iron cooled till it can no longer be seen in the dark.

Besides the arrangement in the order of my experiments which would arise from this division, we have another subject to consider. For, since the chief design of this paper is to give a comparative view of the operations that may be performed on the rays that occasion heat, and of those which we already know to have been effected on the rays that occasion light, it will be necessary to take a short review of the latter. I shall merely select such facts as not only are perfectly well known, but especially such as will answer the intention of my comparative view, and arrange them in the following order.

1. Light, both solar and terrestrial, is a sensation occasioned by rays emanating from luminous bodies, which have a power of illuminating objects; and, according to circumstances, of making them appear of various colours.

2. These rays are subject to the laws of reflection.

3. They are likewise subject to the laws of refraction.

4. They are of different refrangibility.

5. They are liable to be stopped, in certain proportions, when transmitted through diaphanous bodies.

6. They are liable to be scattered on rough surfaces.

7. They have hitherto been supposed to have a power of heating bodies; but this remains to be examined.

The similar propositions relating to heat, which are intended to be proved in this paper, will stand as follows.

1. Heat, both solar and terrestrial, is a sensation occasioned by rays emanating from candent substances, which have a power of heating bodies.

2. These rays are subject to the laws of reflection.

3. They are likewise subject to the laws of refraction.

4. They are of different refrangibility.

5. They are liable to be stopped, in certain proportions, when transmitted through diaphanous bodies.

6. They are liable to be scattered on rough surfaces.

7. They may be supposed, when in a certain state of energy, to have a power of illuminating objects; but this remains to be examined.

Before I can go on, I have to mention, that the number of experiments which will be required to make good all these points, exceeds the usual length of my papers; on which account, I shall divide the present one into two parts. Proceeding therefore now to an investigation of the three first heads that have been proposed, I reserve the three next, and a discussion which will be brought on by the seventh article, for the second part.

1st. Experiment. Reflection of the Heat of the Sun.

I exposed the thermometer which in a former paper has been denoted by No. 3, to the eye-end of a ten-feet NEWTONIAN

telescope, which carried a *Camera-eye-piece*,* but no eye-glass. When, by proper adjustment, the focus came to the ball of the thermometer, it rose from 52 degrees to 110; so that rays which came from the sun, underwent three regular reflections; one, on a concave mirror, and the other two, on two plain ones. Now these rays, whether they were those of light or not, for that our experiment cannot ascertain, had a power of occasioning heat, which was manifested in raising the thermometer 58 degrees.

2d. Experiment. Reflection of the Heat of a Candle.

At the distance of 29 inches from a candle, I planted a small steel-mirror, of $3\frac{4}{10}$ inches diameter, and about $2\frac{1}{4}$ inches focal length.† In the secondary focus of it, I placed the ball of the thermometer which in my paper has been marked No. 2; and very near it, but out of the reach of reflection, the thermometer No. 3. Having covered the mirror till both were come to the temperature of their stations, I began as follows.

	No. 2. In the Focus.	No. 3. Standard.
0′	54	54
1	55	54
2	56	54
3	57	54
4	$57\frac{1}{4}$	54
5	$57\frac{1}{4}$	54

Here, in five minutes, the thermometer No. 2 received $3\frac{1}{4}$ degrees of heat from the candle, by reflected rays. I now

* See Phil. Trans. Vol. LXXII. p. 176.

† See Plate XII. Fig. 1.

covered the mirror, but left all the rest of the apparatus untouched.

	No. 2. In the Focus.	No. 3. Standard.
0′	$57\frac{1}{4}$	54
1	$55\frac{1}{2}$	54
$1\frac{1}{2}$	55	54
6	54	54

Here, in six minutes, the thermometer lost the $3\frac{1}{4}$ degrees of heat again, which it had gained before. I uncovered the mirror once more.

0′	54	54
$1\frac{1}{2}$	56	54
$3\frac{1}{2}$	57	54
5	$57\frac{1}{4}$	54

And, in five minutes, the $3\frac{1}{4}$ degrees of heat were regained. In consequence of which, we are assured that certain rays came from the candle, subject to the laws of reflection, which, though they might not be the rays of light, for that our experiment does not determine, were evidently invested with a power of heating the thermometer placed in the focus of the mirror.

3d Experiment. Reflection of the Heat that accompanies the Solar prismatic Colours.

In the spectrum of the sun, given by a prism, I placed my small steel mirror, with a thermometer in its focus.* It was covered by a piece of pasteboard, which, through a proper opening, admitted all the visible colours to fall on its polished surface, but excluded every other ray of heat that might be, either on the violet or on the red side, beyond the spectrum.

* See Plate XII. Fig. 2.

Then, placing the apparatus so as to have the thermometer in the red rays, but keeping the mirror covered up till the thermometer became settled, I found it stationary at 58°. Uncovering the mirror, I had as follows.

	No. 2.
0′	58
2	93

Here, in two minutes, the thermometer rose 35 degrees, by reflected heat. I covered the mirror again, and, in a few minutes, the thermometer, exposed to the direct prismatic red, came down to 58° again. And thus the prismatic colours, if they are not themselves the heat-making rays, are at least accompanied by such as have a power of occasioning heat, and are liable to be regularly reflected.

4th Experiment. Reflection of the Heat of a red-hot Poker.

I placed the small steel mirror at 12 inches from a red-hot poker, set with its heated end upwards, in a perpendicular position, and so elevated as to throw its rays on the mirror.* The thermometer No. 2 was placed in its secondary focus, and had a small pasteboard screen, to guard its ball from the direct heat of the poker.

	No. 2.
0′	$54\frac{1}{2}$
$1\frac{1}{2}$	93

I covered the mirror.

3′	65

Here, in $1\frac{1}{2}$ minute, the thermometer rose $38\frac{1}{2}$ degrees, by reflected rays; and, when the mirror was covered up, it fell in the next $1\frac{1}{2}$ minute, 28 degrees. On which account, we cannot

* See Plate XII. Fig. 1.

but allow, that certain rays, whether it be those that shine or not, issue from an ignited poker, which are subject to the regular laws of reflection, and have a power of heating bodies.

5th Experiment. Reflection of the Heat of a Coal Fire by a plain Mirror.

I placed a small speculum, such as I use with my 7-feet reflectors, upon a stand, and so as to make an angle of 45 degrees with the front of it.* This was afterwards to face the fire in my parlour chimney, and would make the same angle with the bars of the grate. At a distance of $3\frac{1}{2}$ inches from the speculum, on the reflecting side of it, was placed the thermometer No. 1; and close by it, but out of the reach of the reflected rays, the thermometer No. 4. The whole was guarded in front, against the influence of the fire, by an oaken board $1\frac{1}{2}$ inch thick, which had a circular opening of $1\frac{1}{4}$ inch diameter, opposite the situation of the plain mirror, in order to permit the fire to shine upon it. The thermometers were divided from the mirror by a wooden partition, which also had an opening in it, that the reflected rays might come from the mirror to No. 1, while No. 4 remained screened from their influence. On exposing this apparatus to the fire, I had the following result.

	No. 1.	No. 4.
0′	60	60
1	62	60
2	64	60
3	66	60
4	66	60
5	67	$60\frac{1}{2}$

* See Plate XII. Fig. 3.

Here, in five minutes, the heat reflected from the plain mirror raised the thermometer No. 1, 7 degrees; while the change in the temperature of the screened place, indicated by No. 4, amounted only to half a degree: which shews, that an open fire sends out rays that are subject to the laws of reflection, and occasion heat.

6th Experiment. Reflection of Fire-heat by a Prism.

Every thing remaining arranged as in the 5th experiment, I removed the small plain mirror, and placed in its stead a prism, which had one of its angles of 90 degrees, and the other two of 45° each.* It was put so as to have one of the sides facing the fire, while the other was turned towards the thermometer: the hypotenuse, consequently, made an angle of 45 degrees with the bars of the grate. The apparatus, after having been cooled some time, was exposed to the fire, and the following result was taken.

	No. 1.	No. 4.
0′	$62\frac{1}{2}$	$62\frac{1}{2}$
1	63	$62\frac{3}{4}$
2	64	63
4	$64\frac{1}{2}$	63
5	65	$63\frac{1}{4}$
8	$65\frac{3}{4}$	$63\frac{1}{2}$
10	$66\frac{1}{2}$	$63\frac{3}{4}$
11	67	$64\frac{1}{4}$

Here, in eleven minutes, the rays reflected by the prism raised the thermometer $4\frac{1}{2}$ degrees; but, the temperature of the place having undergone an alteration of $1\frac{3}{4}$ degrees, we can only

* See Plate XII. Fig. 3.

place $2\frac{3}{4}$ to the account of reflection. The apparatus becoming now very hot, it would not have been fair to have continued the experiment for a longer time; but the effect already produced was fully sufficient to shew, that even a prism, which stops a great many heat-making rays, still reflects enough of them to prove, that an open fire not only sends them out, but that they are subject to every law of reflection.

7th Experiment. Reflection of invisible Solar Heat.

On a board of about 4 feet 6 inches long, I placed at one end, a small plain mirror, and at the other, two thermometers*. The distance of No. 1, from the face of the mirror, was 3 feet $9\frac{3}{4}$ inches; and No. 2 was put at the side of it, facing the same way, but out of the reach of the rays that were to be reflected by the mirror. The colours of the prism were thrown on a sheet of paper having parallel lines drawn upon it, at half an inch from each other. The mirror was stationed upon the paper; and was adjusted in such a manner as to present its polished surface, in an angle of 45 degrees, to the incident coloured rays, by which means, they would be reflected towards the ball of the thermometer No. 1. In this arrangement, the whole apparatus might be withdrawn from the colours to any required distance, by attending to the last visible red colour, as it shewed itself on the lines of the paper. When the thermometers were properly settled to the temperature of their situation, during which time the mirror had been covered, the apparatus was drawn gently away from the colours, so far as to cause the mirror, which was now open, to receive only the invisible rays of heat which lie beyond the confines of red. The result was as follows.

* See Plate XII. Fig. 4.

	No. 1.	No. 2.
0′	56	56
—	57	56
—	59	56
7	60	56
10	60	56

Here, in ten minutes, the thermometer No. 1 received four degrees of heat, reflected to it, in the strictest optical manner, by the plain mirror of a NEWTONIAN telescope. The great regularity with which these invisible rays obeyed the law of reflection, was such, that Dr. WILSON's sensible thermometer No. 2, which had been chosen on purpose for a standard, and was within an inch of the other thermometer, remained all the time without the least indication of any change of temperature that might have arisen from straggling rays, had there been any such. I now took away the mirror, but left every thing else in the situation it was. The effect of this was thus.

	No. 1.	No. 2.
0′	60	56
5	58	56
8	57	56
10	56	56

Here, in ten minutes, the thermometer No. 1 lost again the 4 degrees it had acquired, while No. 2 still remained unaltered; and this becomes therefore a most decisive experiment, in proof of the existence of invisible rays, of their being subject to the laws of reflection, and of their power of occasioning heat.

8th Experiment. Reflection, and Condensation, of the invisible solar Rays.

I made an apparatus for placing the small steel mirror at any required angle;* and, having exposed it to the prismatic spectrum, so as to receive it perpendicularly, I caused the colours to fall on one half of the mirror, which, being covered by a semicircular piece of pasteboard, would stop all visible rays, so that none of them could reach the polished surface. On the pasteboard were drawn several lines, parallel to the diameter, and at the distance of one-tenth of an inch from each other; that, by withdrawing the apparatus, I might have it at option to remove the last visible red to any required distance from the reflecting surface. In the focus of the mirror was placed the thermometer No. 2. I covered now also the other half of the mirror, till the thermometer had assumed the temperature of its situation. Then, withdrawing the apparatus out of the visible spectrum, till the last tinge of red was one-tenth of an inch removed from the edge of the pasteboard, and the whole of the coloured image thus thrown on the semicircular cover, I opened the other half of the mirror, for the admission of invisible rays. The result was as follows.

	No. 2.
	In the Focus of invisible Heat.
0'	61
1	80

Here, in one minute, the thermometer rose 19 degrees. I covered the mirror.

2'	72
3	67
4	64

* See Plate XII. Fig. 2.

Here, in three minutes, the thermometer fell 16 degrees. I opened the mirror again.

No. 2.

In the Focus of invisible Heat.

5′	83
6	88

Here, in two minutes, the thermometer rose 24 degrees. I covered the mirror once more.

7′	69

And, in one minute, the thermometer fell 19 degrees. Now, by this alternate rising and falling of the thermometer, three points are clearly ascertained. The first is, that there are invisible rays of the sun. The second, that these rays are not only reflexible, in the manner which has been proved in the foregoing experiment, but that, by the strict laws of reflection, they are capable of being condensed. And, in the third place, that by condensation, their heating power is proportionally increased; for, under the circumstances of the experiment, we find that it extended so far as to be able to raise the thermometer, in two minutes, no less than 24 degrees.

9th Experiment. Reflection of invisible culinary Heat.

I planted my little steel mirror upon a small board;* and at a proper distance opposite to it I erected a slip of deal, $\frac{1}{2}$ inch thick, and 1 inch broad, in a horizontal direction, so as to be of an equal height, in the middle of its thickness, with the centre of the mirror. Against the side, facing the mirror, were fixed the two thermometers No. 2 and No. 3, with their balls within half an inch of each other, and the scales turned the opposite way. A little of the wood was cut out of the slip, to

* See Plate XIII. Fig. 1.

make room for the balls to be freely exposed. That of No. 2 was in the axis of the mirror; and the ball of No. 3 was screened from the reflected rays, by a small piece of pasteboard tied to the scale. The small ivory scales of the thermometers, with the slip of wood at their back, which however was feather-edged towards the stove, intercepted some heat; but it will be seen presently that there was enough to spare. When my stove was of a good heat, I brought the apparatus to a place ready prepared for it.

	No. 2. In the Focus.	No. 3. Screened.
0'	52	52
1	91	53

Here we find that, in one minute, the invisible culinary heat raised the thermometer No. 2, 39 degrees; while No. 3, from change of temperature, rose only one, notwithstanding its exposure to the stove was in every respect equal to that of No. 3, except so far as relates to the rays returned by the mirror; and therefore, the radiant nature of these invisible rays, their power of heating bodies, and their being subject to the laws of reflection, are equally established by this experiment.

10th *Experiment. Reflection of the invisible Rays of Heat of a Poker, cooled from being red-hot till it could no longer be seen in a dark Place.*

The great abundance of heat in my last experiment, would not allow of its being carried on without injury to the thermometer, the scale of which is not extensive; I therefore placed a poker, when of a proper black heat, at 12 inches from the steel mirror,* and received the effect of its condensed rays upon the

* See Plate XII. Fig. 1.

thermometer No. 2, placed in the focus. Then, alternately covering and uncovering the mirror, one minute at a time, the effect was as follows.

		No. 2.
The mirror covered	0′	61
Open - -	1	68
Covered -	2	61
Open - -	3	64
Covered -	4	59
Open - -	5	$61\frac{1}{2}$
Covered -	6	58.

Here, in six minutes, we have a repeated result of alternate elevations and depressions of the thermometer, all of which confirm the reflexibility, the radiant nature, and the heating power, of the invisible rays that came from the poker.

From these experiments it is now sufficiently evident, that in every supposed case of solar and terrestrial heat, we have traced out rays that are subject to the regular laws of reflection, and are invested with a power of heating bodies; and this independent of light. For though, in four cases out of six, we had illuminating as well as heating rays, it is to be noticed that our proof goes only to the power of occasioning heat, which has been strictly ascertained by the thermometer. If it should be said, that the power of illuminating objects, of these same rays, is as strictly proved by the same experiments, I must remark, that from the cases of invisible rays brought forward in the four last experiments, it is evident that the conclusion, that rays must have illuminating power, because they have a power of occasioning heat, is erroneous; and, as this must be admitted, we have a right to ask for some proof of the assertion, that rays

which occasion heat can ever become visible. But, as we shall have an opportunity to say more of this hereafter, I proceed now to investigate the refraction of heat-making rays.

11th Experiment. Refraction of solar Heat.

With a new ten-feet NEWTONIAN telescope, the mirror of which is 24 inches in diameter of polished surface, I received the rays of the sun; and, making them pass through a day-piece with four lenses, I caused them to fall on the ball of the thermometer No. 3, placed in their focus. Those who are acquainted with the lines in which the principal rays and pencils move through a set of glasses, will easily conceive how artfully, in our present instance, heat was sent from one place to another. Heat crossing heat, through many intersecting courses, without jostling together, and each parcel arriving at last safely to its destined place. As soon as the rays were brought to the thermometer, it rose almost instantly from 60 degrees to 130; and, being afraid of cracking the glasses, I turned away the telescope. Here the rays, which occasioned no less than 70 degrees of heat, had undergone eight regular successive refractions; so that their being subject to its laws cannot be doubted.

12th Experiment. Refraction of the Heat of a Candle.

I placed a lens of about 1,4 inch focus, and 1,1 diameter, mounted upon a small support, at a distance of 2,8 inches from a candle;* and the thermometer No. 2, behind the lens, at an equal distance of about 2,8 inches; but which ought to be very carefully adjusted to the secondary focus of the candle. Not far from the lens, towards the candle, was a pasteboard screen, with an aperture of nearly the same size as the lens. The sup-

* See Plate XIII. Fig. 2.

port of the lens had an eccentric pivot, on which it might be turned away from its place, and returned to the same situation again, at pleasure. This arrangement being made, the thermometer was for a few moments exposed to the rays of the candle, till it had assumed the temperature of its situation. Then the lens was turned on its pivot, so as to intercept the direct rays, which passed through the opening in the pasteboard screen, and to refract them to the focus, in which the thermometer was situated.

	No. 2.
0′	$53\frac{7}{8}$
1	$55\frac{1}{2}$
2	$55\frac{3}{4}$
3	56

Here, in three minutes, the thermometer received $2\frac{1}{8}$ degrees of heat, by the refraction of the lens. The lens was now turned away.

0′	56
1	$54\frac{5}{8}$
2	$54\frac{1}{8}$
3	$53\frac{7}{8}$

Here, in three minutes, the thermometer lost $2\frac{1}{8}$ degrees of heat. The lens was now returned to its situation.

0′	$53\frac{7}{8}$
1	$54\frac{3}{4}$
2	$55\frac{1}{8}$
3	56

And, in three minutes, the thermometer regained the $2\frac{1}{8}$ degrees of heat. A greater effect may be obtained by a different

arrangement of the distances. Thus, if the lens be placed at $3\frac{1}{2}$ inches from a wax-candle, and the thermometer situated, as before, in the secondary focus, we shall be able to draw from 5 to 8 degrees of heat, according to the burning of the candle, and the accuracy of the adjustment of the thermometer to the focus. The experiment we have related shews evidently, that rays invested with a power of heating bodies, issue from a candle, and are subject to laws of refraction, nearly the same with those respecting light.

13th Experiment. Refraction of the Heat that accompanies the coloured part of the prismatic Spectrum.

I covered a burning lens of Mr. DOLLOND's, which is nearly 9 inches in diameter, and very highly polished, with a piece of pasteboard, in which there was an opening of a sufficient size to admit all the coloured part of the prismatic spectrum.* In the focus of the glass was placed the thermometer No. 3; and, when every thing was arranged properly, I covered the lens for five minutes, that the thermometer might assume the temperature of its situation. The result was as follows.

		No. 3.
The lens covered	0′	64
Open - -	1	176

Here, in one minute, the thermometer received 112 degrees of heat, which came with the coloured part of the solar spectrum, and were refracted to a focus; so that, if the coloured rays themselves are not of a heat-making nature, they are at least accompanied with rays that have a power of heating bodies, and

* See Plate XIV.

are subject to certain laws of refraction, which cannot differ much from those affecting light.

14th Experiment. Refraction of the Heat of a Chimney-Fire.

I placed Mr. Dollond's lens before the clear fire of a large grate.* Its distance from the bars of the grate was three feet; and, in the secondary focus of it was placed the thermometer No. 1. No. 4 was stationed, by way of standard, at $2\frac{1}{2}$ inches from the former, and at an equal distance from the fire. Before the thermometers was a slip of mahogany, which had three holes in it, $\frac{8}{10}$ of an inch in diameter each. Behind the centre of the 1st hole, $\frac{3}{8}$ of an inch from the back, was placed the thermometer No. 1; and, between the 2d and 3d hole, guarded from the direct rays of the fire by the partition, at the same distance from the back, was put No. 4. Things being thus arranged, the situation of the apparatus which carried the thermometers, and that where the lens was fixed, were marked. Then the thermometers, having been taken away to be cooled, were restored to their places again, and their progress marked as follows.

	No. 1. Burning Lens.	No. 4. Screened.
0'	58	58
$1\frac{1}{2}$	65	60
3	68	61
5	70	$61\frac{1}{2}$
7	$71\frac{1}{4}$	$61\frac{3}{4}$
9	$71\frac{1}{2}$	$61\frac{1}{4}$

Here, in nine minutes, the rays coming from the fire, through the burning glass, gave $9\frac{1}{4}$ degrees of heat more to the ther-

* See Plate XV.

mometer No. 1, than No. 4, from change of temperature, had received behind the screen. Now, to determine whether this was owing merely to a transmission of heat through the glass, or to a condensation of the rays, by the refraction of the burning lens, I took away the lens, as soon as the last observation of the thermometers was written down, and continued to take down their progress as follows.

	No. 1.	No. 4.
9′$\frac{1}{2}$	71$\frac{1}{2}$	61$\frac{3}{4}$
11	70$\frac{1}{2}$	61$\frac{3}{4}$
12	70$\frac{1}{4}$	61$\frac{3}{4}$
—	69$\frac{1}{2}$	61$\frac{3}{4}$
14$\frac{1}{2}$	69$\frac{1}{4}$	61$\frac{3}{4}$

Here the direct rays of the fire, we see, could not keep up the thermometer No. 1; which lost 2$\frac{1}{4}$ degrees of heat, notwithstanding the lens intercepted no longer any of them. I now restored the burning glass, and continued.

15′	69$\frac{1}{4}$	61$\frac{3}{4}$
16	69$\frac{1}{2}$	61$\frac{3}{4}$
17	70	61$\frac{3}{4}$
20	70$\frac{3}{4}$	61$\frac{3}{4}$
25	71	61$\frac{3}{4}$

Here again, the lens acted as a condenser of heat, and gave 1$\frac{3}{4}$ degrees of it to the thermometer No. 1. I now once more took away the lens, and continued the experiment.

25′$\frac{1}{2}$	71	61$\frac{3}{4}$
31	68	61$\frac{3}{4}$

This again confirms the same, by a loss of 3 degrees of heat. I restored the lens once more, and had as follows.

	No. 1. Burning Lens.	No. 4. Screened.
31′½	68	61¾
35	69½	61¾

And here the thermometer received 1½ degree of heat again; so that, in the course of 35 minutes, the thermometer No. 1 was alternately raised and depressed five times, by rays which came from the chimney fire, and were subject to laws of refraction, not sensibly different from those which affect light.

15th Experiment. Refraction of the Heat of red-hot Iron.

I caused a lump of iron to be forged into a cylinder of 2½ inches diameter, and 2½ inches long.* This, being made red-hot, was stuck upon an iron handle fixed on a stand, so as to present one of its circular faces to a lens placed at 2,8 inches distance; its focus being 1,4 inch, and diameter 1,1. Before the lens, at some distance, was placed a screen of wood, with a hole of an inch diameter in it, by way of limiting the object, that its image in the focus might not be larger than necessary. The screen also served to keep the heat from the thermometers. No. 2 was situated in the secondary focus of the lens; and No. 3 was placed within $\frac{3}{10}$ of an inch of it, and at the same distance from the lens as No. 2. By this arrangement, both thermometers were equally within the reach of transmitted heat; or, if there was any difference, it could only be in favour of No. 3, as being behind a part of the lens which, on account of its thinness, would stop less heat than the middle. Now, as the experiment gives a result which differs from what would have arisen from the situation of the thermometers, on a supposition of transmitted heat, we can only ascribe it to a conden-

* See Plate XVI. Fig. 1.

sation of it by the refraction of the lens; and, in this case, the thermometer No. 3, by its situation, must have been partly within the reach of the heat-image formed in the focus. During the experiment, the thermometers were alternately screened two minutes from the effects of the lens, and exposed to it for the same length of time; and the result was as follows.

		No. 2 In the Focus.	No. 3. Near the Focus.
Screened	0′	56	56
Open	2	62	60
Screened	4	59	58
Open	6	61	59
Screened	8	$58\frac{1}{4}$	$57\frac{3}{4}$
Open	10	$59\frac{1}{2}$	$58\frac{1}{4}$

Here, in the first and second minutes, No. 2 gained two degrees of heat more than No. 3. In the third and fourth, it lost one more than No. 3. In the fifth and sixth, it gained one more. In the seventh and eighth, it lost $1\frac{1}{2}$ more; and in the ninth and tenth, it gained $\frac{3}{4}$ more than the other thermometer. This plainly indicates its being acted upon by refracted heat. Lest there should remain a doubt upon the subject, I now removed the lens, and, putting a plain glass in the room of it, I repeated the experiment, with all the rest of the apparatus in its former situation.

Screened	0′	$57\frac{1}{4}$	$56\frac{3}{4}$
Open	2	$62\frac{1}{4}$	$61\frac{3}{4}$
Screened	4	$60\frac{1}{2}$	60
Open	6	61	$60\frac{1}{2}$
Screened	8	60	$59\frac{1}{2}$
Open	10	$60\frac{4}{3}$	$60\frac{1}{4}$

Here we find, that both thermometers received heat and parted with it always in equal quantities, which confirms the experiment that has been given. And thus it is evident, that there are rays issuing from red-hot iron, which are subject to laws of refraction, nearly equal to those which affect light; and that these rays are invested with a power of causing heat in bodies.

16th Experiment. Refraction of Fire-heat, by an Instrument resembling a Telescope.

It occurred to me, that I might use a concave mirror, to condense the heat of the fire in the grate of my chimney, and, reflecting it sideways by a plain mirror, I might afterwards bring it to a secondary focus by a double convex lens; and that, by this construction, I should have an instrument much like a NEWTONIAN telescope.* The thermometer would figuratively become the observer of heat, by being applied to the place where, in the real telescope of the same construction, the eye is situated to receive light. Having put together the different parts, in such a way as I supposed would answer the end, I tried the effect by a candle, in order to ascertain the proper distance of the object-mirror from the bars of the chimney-grate. The front of the apparatus was guarded by an iron plate, with a thick lining of wood; and the two thermometers which I used, were parted from the mirrors and lens by a partition, which screened them from the heat that was to be admitted through a proper opening in the front plate, to come at the object-mirror. In the partition was likewise an opening, of a sufficient diameter to permit the rays to come from the eye-glass to their focus, on the ball of the thermometer No. 1; while

* See Plate XVI. Fig. 2.

No. 4 was placed by the side of it, at less than half an inch distance. In the experiment, the object-mirror was alternately covered by a piece of pasteboard, and opened again. The thermometers were read off every minute; but, to shorten my account, I only give the last minute of every change.

		No. 1. In the Focus.	No. 4. Near the Focus.
The mirror covered	0′	77½	77½
The mirror open	8	84	76
Covered - -	16	86½	79½
Open -	21	89¾	81
Covered -	27	89¼	82¼
Open - -	37	91½	83½
Covered -	47	84	77

Here, in the first eight minutes, the thermometer exposed to the effects of the fire-instrument, gained 2 degrees of heat more than the other. In the next 8 minutes, the mirror being covered, it gained 1 degree less than the other. The mirror being now opened again, it gained, in 5 minutes, 2¼ degrees more than the other. When covered 6 minutes, it gained 1¼ degree less than No. 4. In the next 10 minutes, when open, it gained ½ degree more; and, in the last 10 minutes, when the fire began to fail, and the mirror was again covered, it lost 1 degree more than the other thermometer. All which can only be accounted for by the heat which came to the thermometer through the fire-instrument; and, as this experiment confirms what has been said before of the refraction of culinary heat, so it also adds to what has already been proved of its reflection. For, in this fire-instrument, the rays which occasion heat could undergo no less than two reflections and two refractions.

17th Experiment. Refraction of the invisible Rays of solar Heat.

I covered one half of Mr. DOLLOND's burning lens with pasteboard, and threw the prismatic spectrum upon that cover;* then, keeping the last visible red colour one-tenth of an inch from the margin of the pasteboard, I let the invisible rays beyond the spectrum fall on the lens. In the focus of the red rays, or a very little beyond it, I had placed the ball of the thermometer No. 1; and, as near to it as convenient, the small one No. 2. Now, that the invisible solar rays which occasion heat were accurately refracted to a focus, may be seen by the following account of the thermometers.

	No. 1. In the Focus.	No. 2. Near the Focus.
0′	57	57
1	102	57

Here, in one minute, these rays gave 45 degrees of heat to the thermometer No. 1, which received them in the focus, while the other, No. 2, suffered no change.

It is remarkable, that notwithstanding I kept the red colour of the spectrum $\frac{1}{10}$ of an inch upon the pasteboard, a little of that colour might still be seen on the ball of the thermometer. This occasioned a surmise, that possibly the invisible rays of the sun might become visible, if they were properly condensed; I therefore put this to the trial, as follows.

18th Experiment. Trial to render the invisible Rays of the Sun visible by Condensation.

Leaving the arrangement of my apparatus as in the last experiment, I withdrew the lens, till the last visible red colour

* See Plate XIV.

was two-tenths of an inch from the margin of the semicircular pasteboard cover; then, taking the thermometers, I had as follows.

	No. 2.	No. 3.
0′	57	57
1	78	57

Here, there was no longer the least tinge of any colour, or vestige of light, to be seen on the ball of the thermometer; so that, in one minute, it received 21 degrees of heat, from rays that neither were visible before, nor could be rendered so by condensation.

To account for the colour which may be seen in the focus, when the last visible red colour is less than two-tenths of an inch from the margin of the pasteboard which intercepts the prismatic spectrum, we may suppose, that the imperfect refraction of a burning lens, which from its great diameter cannot bring rays to a geometrical focus, will bring some scattered ones to it, which ought not to come there. We may also admit, that the termination of a prismatic spectrum cannot be accurately ascertained, by looking at it in a room not sufficiently dark to make very faint tinges of colour visible. And, to this must be added, that the incipient red rays must actually be scattered over a considerable space, near the confines of the spectrum, on account of the breadth of the prism, the whole of which cannot bring its rays of any one colour properly together; nor can it separate the invisible rays intirely from the visible ones. For, as the red rays will be but faintly scattered in the beginning of the visible spectrum, so, on the other hand, will the invisible rays, separated by the parts of the prism that come next in succession, be mixed with the former red ones. Sir ISAAC

NEWTON has taken notice of some imperfect tinges or haziness, on each side of the prismatic spectrum, and mentions that he did not take them into his measures.*

19th Experiment. Refraction of invisible culinary Heat.

There are some difficulties in this experiment; but they arise not so much from the nature of this kind of heat, as from our method of obtaining it in a detached state. A red-hot lump of iron, when cooled so far as to be no longer visible, has but a feeble stock of heat remaining, and loses it very fast. A contrivance to renew and keep this heat might certainly be made, and I should indeed have attempted to carry some method or other of this kind into execution, had not the following trials appeared to me sufficiently conclusive to render it unnecessary. Admitting, as has been proved in the 15th experiment, that the alternate rising and falling of a thermometer placed in the focus of a lens, when the ball of it is successively exposed to, or screened from, its effects, is owing to the refraction of the lens, and cannot be ascribed to a mere alternate transmission and stoppage of heat, I proceeded as follows.† My lens, 1,4 focus, and 1,1 diameter, being placed 2,8 inches from the face of the heated cylinder of iron, the thermometer No. 2, in its focus, was alternately guarded by a small pasteboard screen put before it, and exposed to the effects of condensed heat by removing it.

		No. 2.	
Screened	0′	55	Very red-hot.
Open	2	$63\frac{1}{2}$	Red-hot.
Screened	4	58	Still red-hot.
Open	6	$60\frac{1}{2}$	Still red.

* NEWTON's Optics, page 23, line 11.

† See Plate XVI. Fig. 1.

		No. 2.	
Screened	8′	$57\frac{1}{2}$	A little red.
Open	10	$59\frac{1}{4}$	Doubtful.
Screened	12	$57\frac{1}{2}$	Not visible in my room darkened.
Open	14	$58\frac{1}{2}$	
Screened	16	$57\frac{1}{2}$	
Open	18	$58\frac{1}{4}$	
Screened	20	$57\frac{1}{4}$	
Open	22	58	
Screened	24	$57\frac{1}{2}$	
Open	26	58	
Screened	28	$57\frac{1}{2}$	

Now, the beginning of this experiment being exactly like that of the 15th, with the thermometer No. 3 left out, the arguments that have before proved the refraction of heat in one state, will now hold good for the whole. For here we have a regular alternate rising and falling of the thermometer, from a bright red heat of the cylinder, down to its weakest state of black heat; where the effect of the rays, condensed by the lens, exceeded but half a degree the loss of those that were stopped by it.

20th Experiment. Confirmation of the 19th.

In order to have some additional proof, besides the uniform and uninterrupted operation of the lens in the foregoing experiment, I repeated the same, with an assistant thermometer, No. 3, placed first of all at $\frac{1}{4}$ of an inch from No. 2, and more towards the lens, but so as to be out of the converging pencil of its rays, and also to allow room for the little screen between the two thermometers, that No. 3 might not be covered by it.

		No. 2. In the Focus.	No. 3. Advanced sideways. Always open.
Screened	0′	$62\frac{1}{2}$	63
Open	1	$63\frac{3}{4}$	64
Screened	2	$62\frac{7}{8}$	64
Open	3	64	$64\frac{1}{2}$
Screened	4	$63\frac{3}{4}$	$64\frac{1}{2}$
Open	5	$64\frac{7}{8}$	$64\frac{1}{2}$
Screened	6	$64\frac{1}{2}$	$64\frac{1}{2}$
Open	7	$64\frac{3}{4}$	64
Screened	8	$64\frac{1}{2}$	64

Here No. 3, being out of the reach of refraction, gradually acquired its maximum of heat, in consequence of an uniform exposure to the influence of the hot cylinder; after which, it began to decline. No. 2, on the contrary, came to its maximum by alternate great elevations, and small depressions; and afterwards lost its heat by great depressions, and small elevations. After the first eight minutes, I changed the place of the assistant thermometer, by putting it into a still more decisive situation; for it was now placed by the side of that in the focus, so as to participate of the alternate screening, and also to receive a small share of one side of the invisible heat-image, which, though unseen, we know must be formed in the focus of the lens. Here, if our reasoning be right, the assistant thermometer should be affected by alternate risings and fallings; but they should not be so considerable as those of the lens.

		No. 2. In the Focus.	No. 3. In the Edge of it.
Both open	8′	$64\frac{1}{2}$	64
Both open	$9\frac{1}{2}$	$63\frac{3}{4}$	$63\frac{3}{4}$

		No. 2. In the Focus.	No. 3. In the Edge of it.
Open -	11	$64\frac{1}{4}$	64
Screened	$12\frac{1}{2}$	63	$63\frac{1}{4}$
Open	14	$63\frac{3}{4}$	$63\frac{1}{2}$
Screened	16	$62\frac{3}{4}$	63
Open	18	$63\frac{3}{4}$	$63\frac{3}{4}$

Here the changes of the thermometer No. 2 were $-\frac{3}{4}+\frac{1}{2}-1\frac{1}{4}+\frac{3}{4}-1+1$; and those of No. 3 were $-\frac{1}{4}+\frac{1}{4}-\frac{3}{4}+\frac{1}{4}-\frac{1}{2}+\frac{3}{4}$. All which so clearly confirm the effect of the refraction of the lens, that it must now be evident that there are rays issuing from hot iron, which, though in a state of total invisibility, have a power of occasioning heat, and obey certain laws of refraction, very nearly the same with those that affect light.

As we have now traced the rays which occasion heat, both solar and terrestrial, through all the varieties that were mentioned in the beginning of this paper, and have shewn that, in every state, they are subject to the laws of reflection and of refraction, it will be easy to perceive that I have made good a proof of the three first of my propositions. For, the same experiments which have convinced us that, according to our second and third articles, heat is both reflexible and refrangible, establish also its radiant nature, and thus equally prove the first of them.

END OF THE FIRST PART.

Slough, near Windsor.
April 26, 1800.

EXPLANATION OF THE FIGURES.

See Plates XII. XIII. XIV. XV. and XVI.

Plate XII. Fig. 1.

Shews the arrangement of the apparatus used in the 2d experiment.

A, is the small mirror with its adjusting screws *m*, *n*.

No. 2, is the thermometer in the focus of the mirror.

No. 3, The assistant thermometer.

B, A small screen for the thermometer No. 2.

C, The candle.

D, The poker which, in the 4th and 10th experiments, is to be placed in the situation of the candle; the rest of the apparatus being brought nearer to it.

Plate XII. Fig. 2.

Shews the apparatus used in the 3d and 8th experiments.

A, The mirror.

No. 2, The thermometer.

BCD, A desk adjustable to different altitudes.

E, The prism receiving the sun's rays through an opening in the window shutter F.

Plate XII. Fig. 3.

AB, is the front of the apparatus, which, in the 5th experiment, is exposed to the fire of the chimney.

C, is the opening in the front plate AB, for the admission of heat.

D, is the small mirror which reflects the rays of heat.

E, is the hole through which the heat passes to the thermometers.

No. 1 and No. 4, are the thermometers.

F, is a prism, which, in the 6th experiment, is to be placed in the room of the mirror D.

Plate XII. Fig. 4.

A, is the board that holds the apparatus used in the 7th experiment.

B, The prism.

C, The spectrum, thrown partly on the paper with parallel lines, and partly on one of the small tables which support the board.

D, The mirror which reflects the rays of heat sideways.

No. 1, The thermometer which receives the reflected rays.

No. 2, The standard thermometer.

Plate XIII. Fig. 1.

AB, is the front which, in the 9th experiment, is put close to the flat side of a heated iron stove.

C, is the mirror.

D, The feather-edged slip of deal, on two pins.

No. 2, The thermometer which receives the rays condensed in the focus of the mirror.

No. 3, The standard thermometer.

E, A small screen tied to No. 3, to guard it from reflected heat.

Plate XIII. Fig. 2.

A, The lens in the apparatus used for the 12th experiment.

No. 2, The thermometer placed in its focus.

B, The screen with an aperture for admitting the rays of heat.

C, The eccentric pivot for turning away the lens.

D, The candle.

Plate XIV.

A, The burning lens, covered; with the prismatic spectrum thrown upon an opening, left for it, in the pasteboard cover of the 13th experiment.

No. 3, The thermometer placed in its focus.

B, The prism.

C, Semicircular cover, used in the 17th and 18th experiments, instead of the one with a square hole.

Plate XV.

A, The burning lens of the 14th experiment.

B, The fire in the chimney.

No. 1, The thermometer in the focus of the lens.

No. 4, The standard thermometer.

C, The hole through which the rays of heat pass to No. 1.

D and E, Two holes, between which the ball of the thermometer No. 4 is screened from the direct rays of the fire; while free access is given to the heat which may affect the temperature of the place.

Plate XVI. Fig. 1.

A, The iron cylinder, stuck upon its handle, as it is used in the 15th and 19th experiments.

B, The lens.

C, The screen with an opening in it.

No. 2, The thermometer in the focus of the lens.

No. 3, The standard thermometer.

D, The little moveable pasteboard screen.

Plate XVI. Fig. 2.

AB, The front, plated with iron, that it may bear to be exposed close to the bars of a chimney fire.

C, The concave mirror.

D, The plain mirror.

E, The lens.

No. 1, The thermometer in the focus of the lens.

No. 4, The standard thermometer.

F, A circular opening in the front plate AB, for admitting the rays of heat to fall on the concave mirror C.

m, The first focus of the rays, from which they go on diverging, to the small mirror, and to the lens; which brings them to a second focus, on the ball of the thermometer No. 1.

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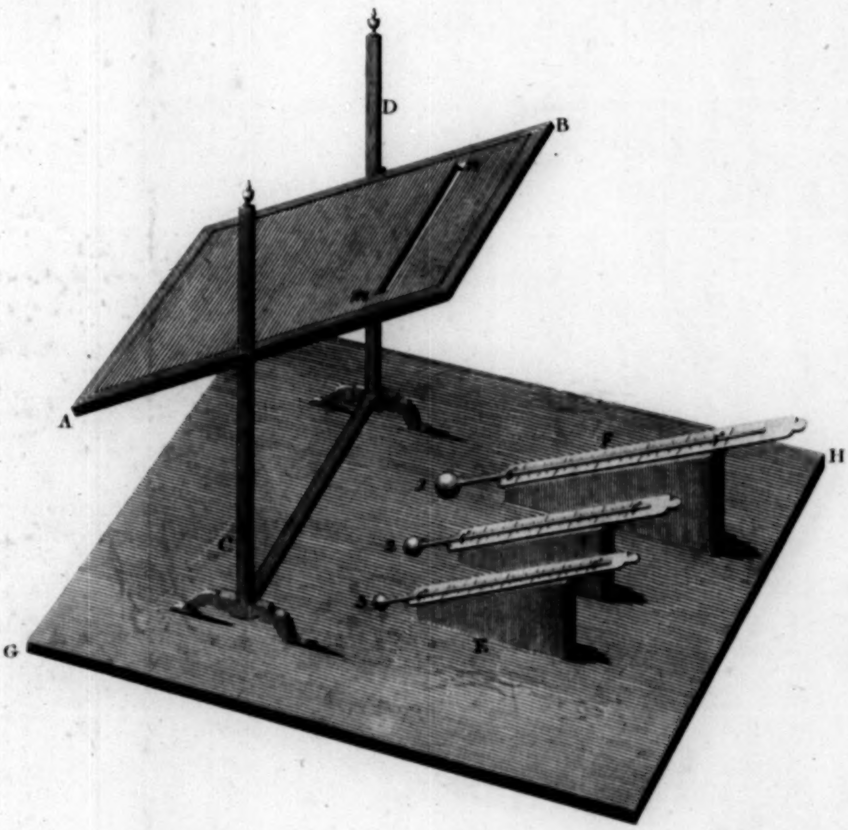

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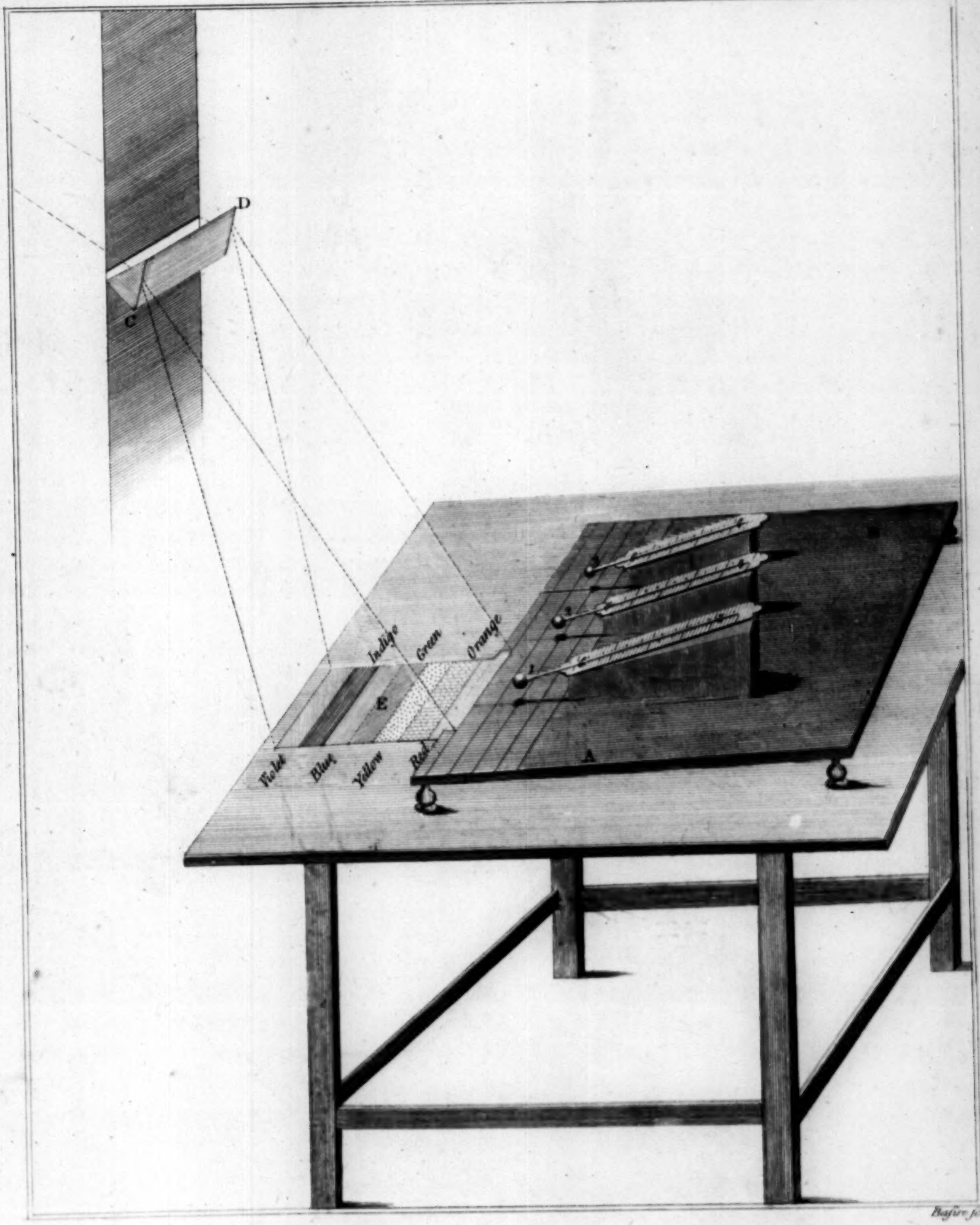

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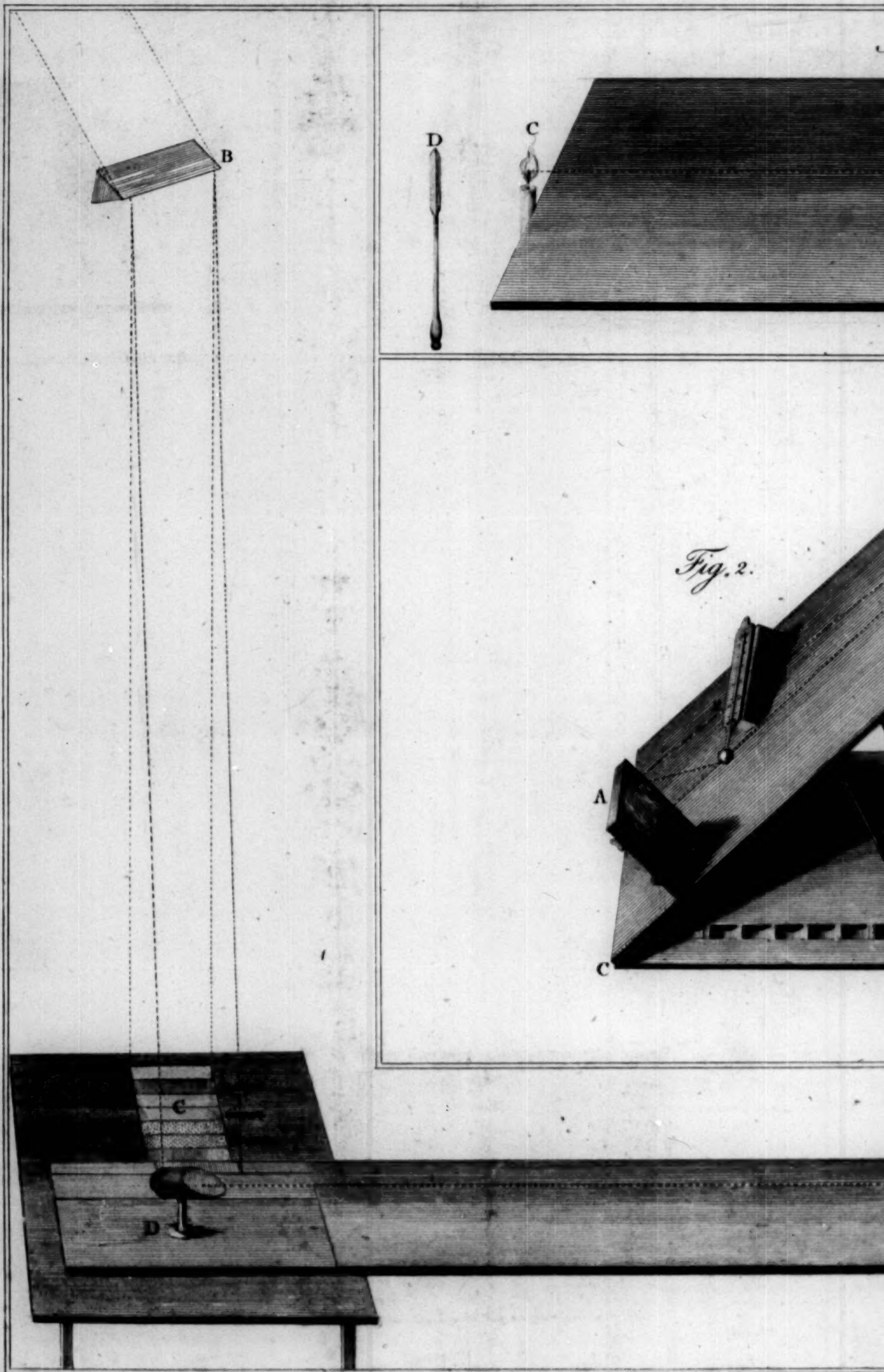
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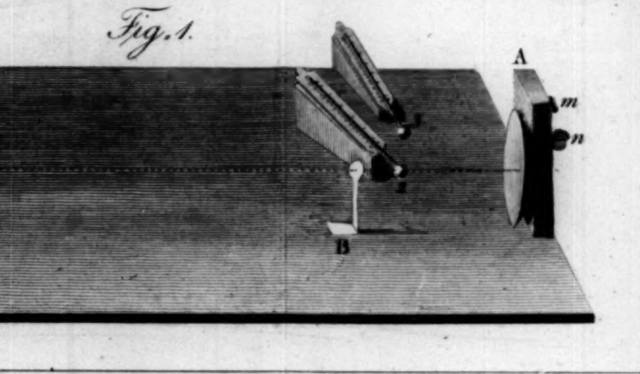

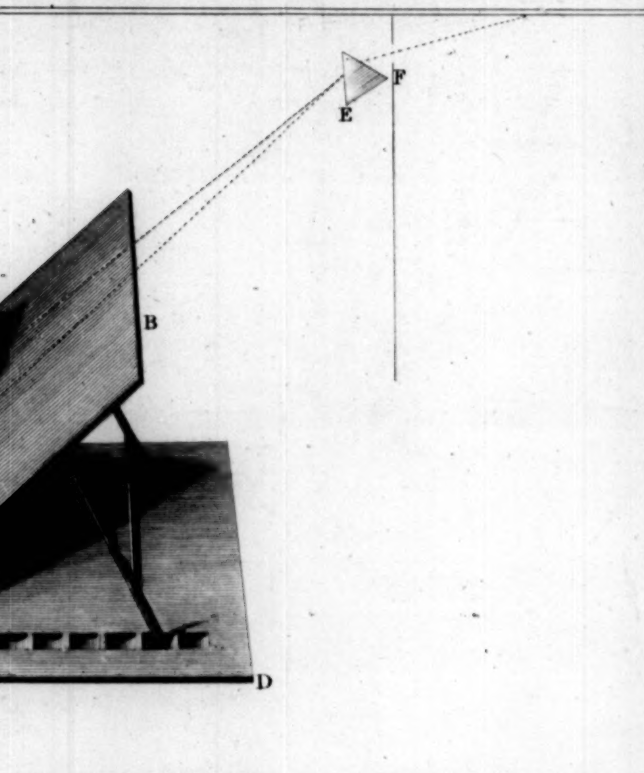

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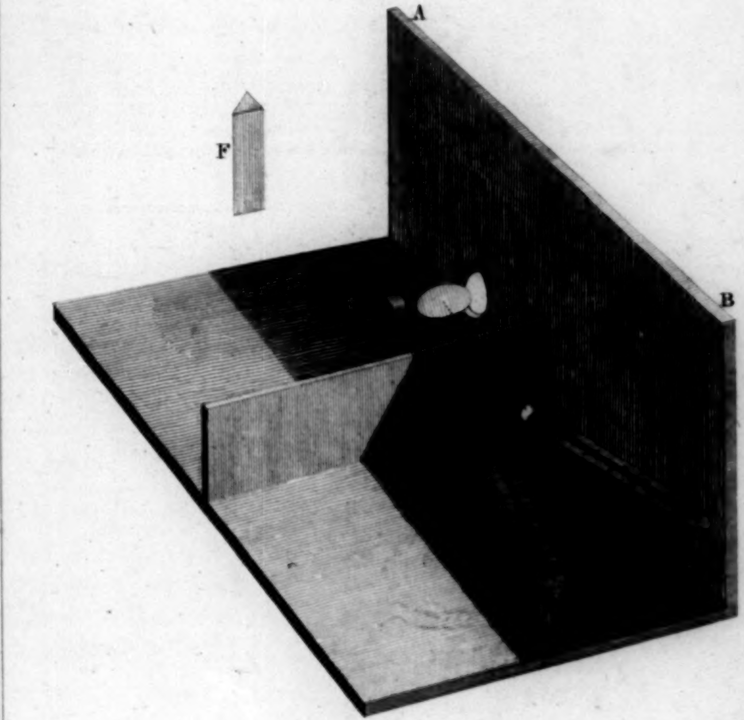

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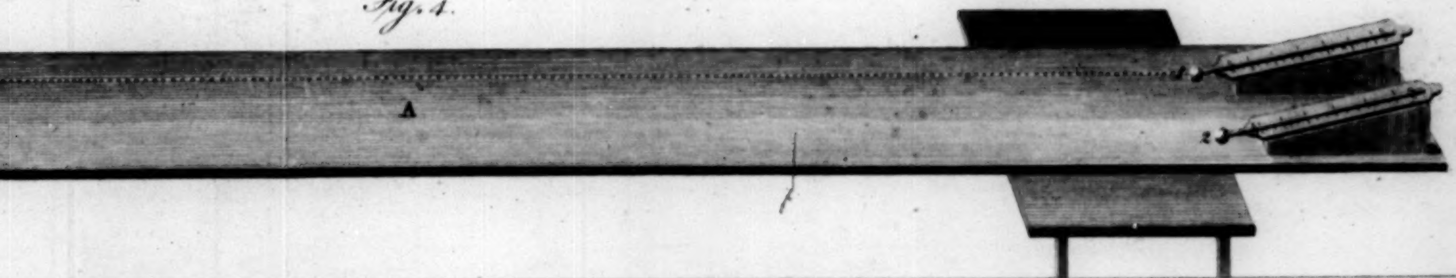

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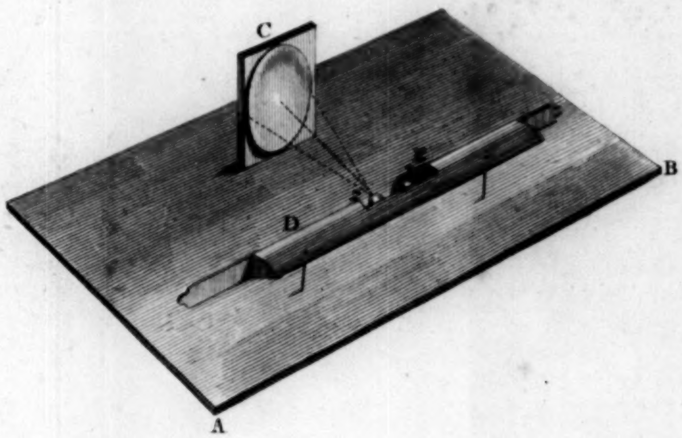

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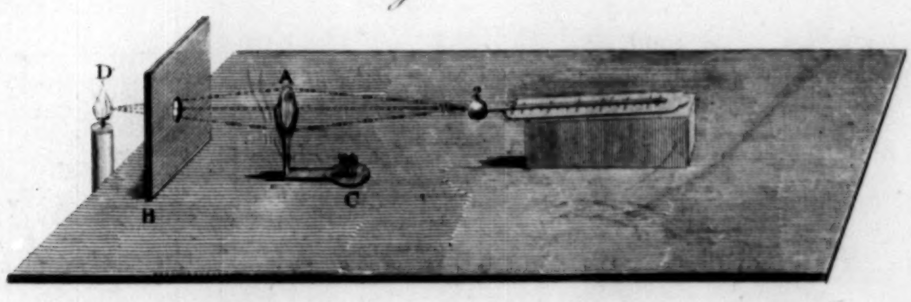

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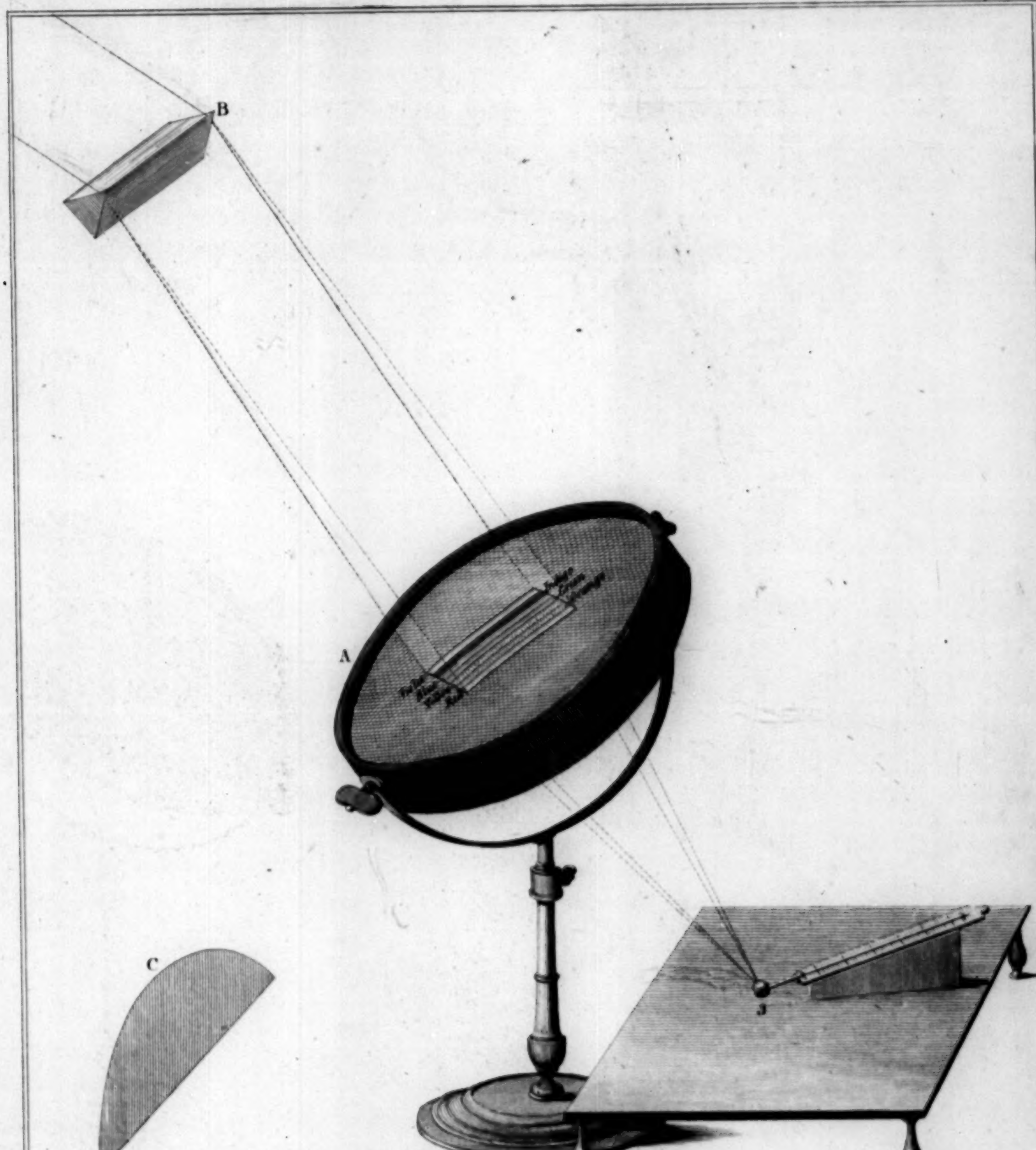

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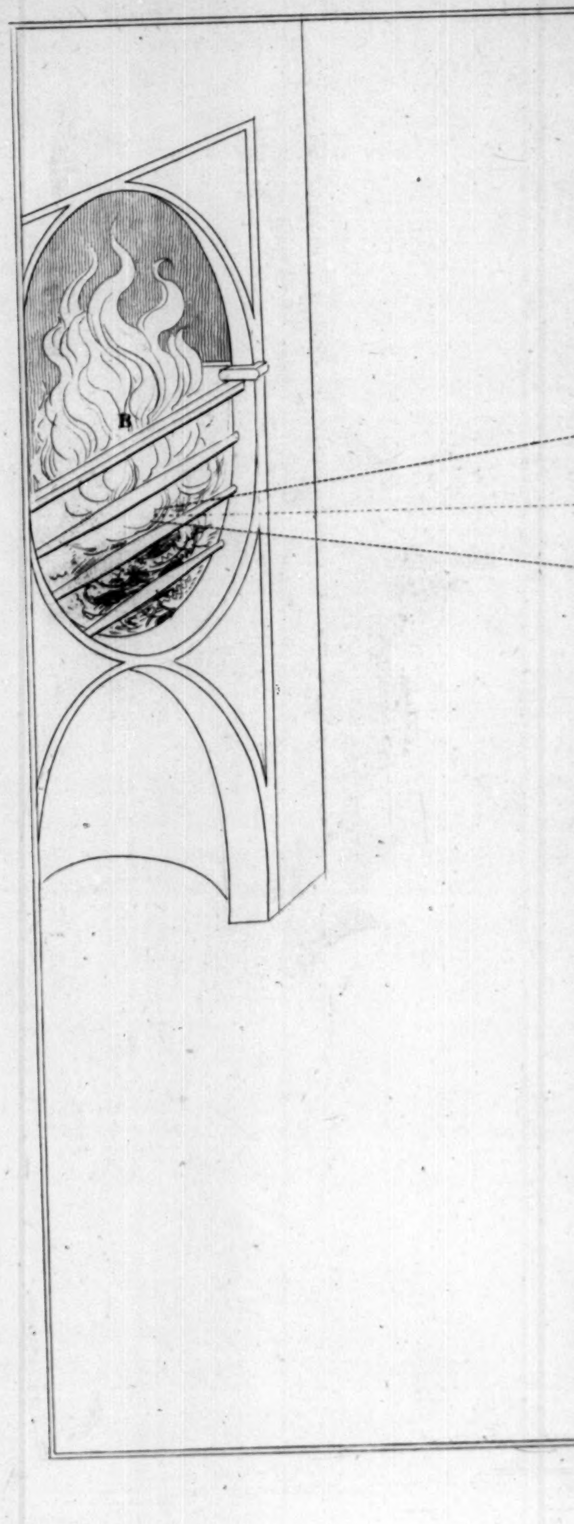
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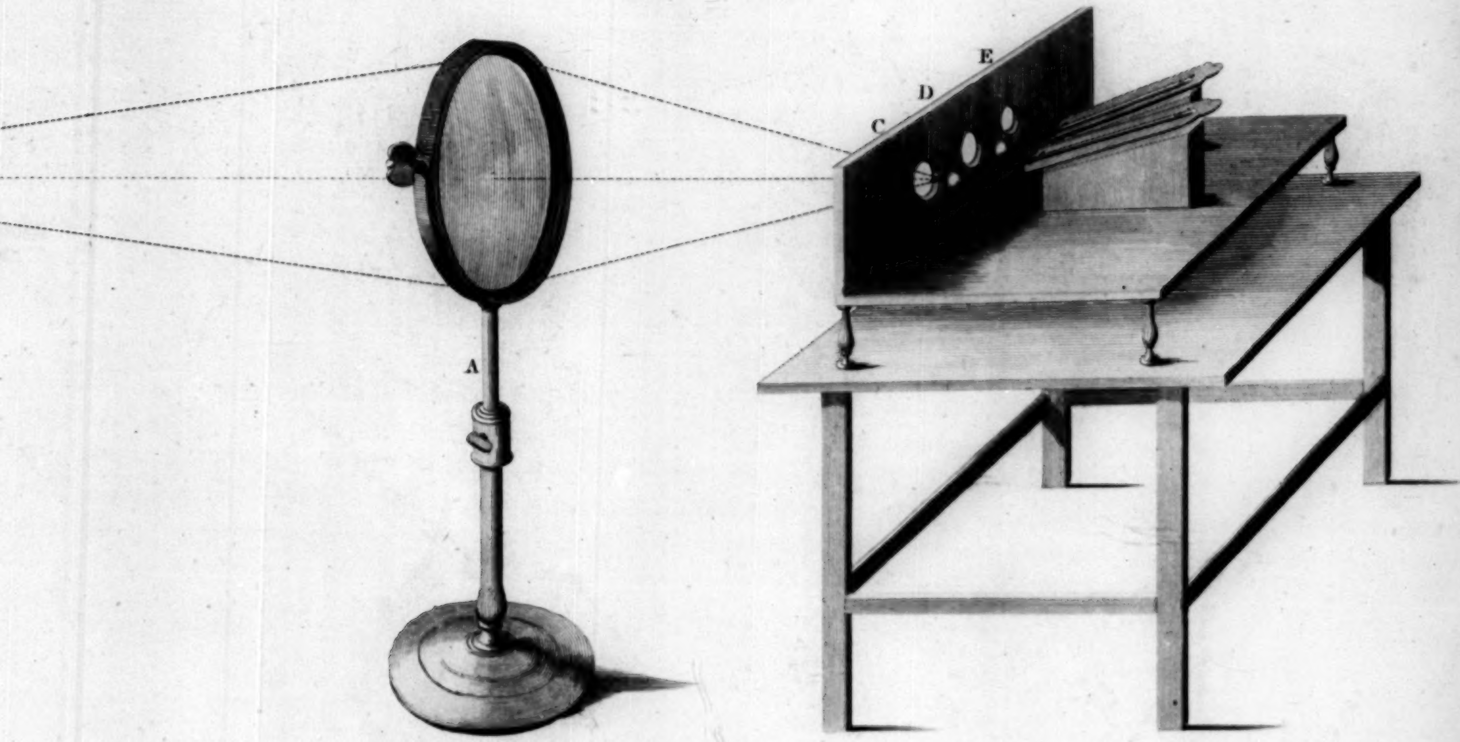

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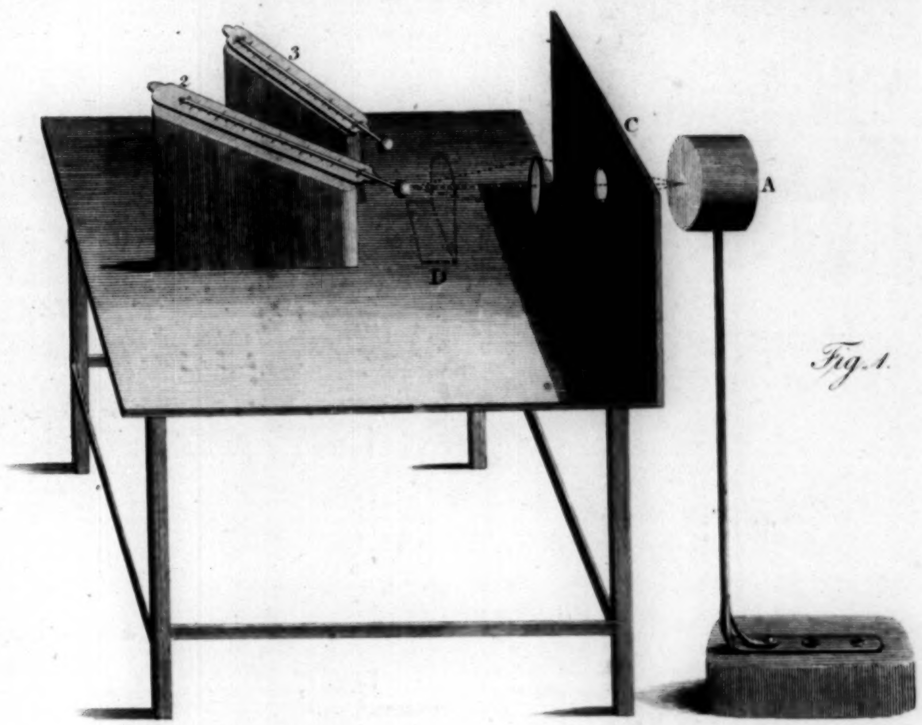

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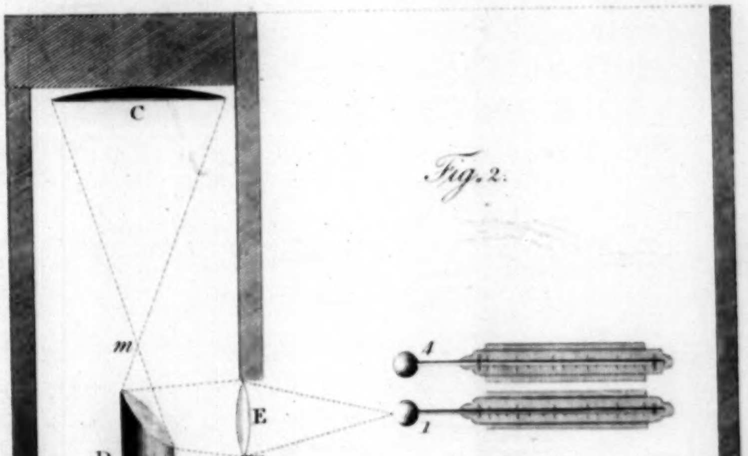

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